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## Article

# Death of distance? Economic implications of infrastructure improvement in Russia

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## ABSTRACT

*We examine the economic implications of infrastructure investment policies that try to improve economic conditions in Russia's peripheral regions.*

*Our analysis of firm-level industrial data for 1989 and 2004 highlights a 'death of distance' in industrial location, with increasing concentration of new firms in regions with good market access. We assess the geographic determinants of growth econometrically and identify market size and proximity to Moscow and regional infrastructure as important drivers of productivity for new and for privately-owned firms. Simulations show that the benefits of infrastructure improvements are highest in the country's capital region where economic activity is already concentrated. Policies that divert public investment towards peripheral regions run the risk of slowing down national economic growth.*

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# Death of distance?

## Economic implications of infrastructure improvement in Russia

*The transport system is a restraining factor for regional development. If we had roads - motor roads, railways - major deposits of mineral resources would have been under development. No roads - no development. People who sometimes have to travel to a neighbouring region via Moscow are experiencing great difficulties. Today we are going to finally agree upon the parameters and key targets of the Federal Transport System Development Program for 2010-2015. I am referring to the largest investment program that has ever been approved by the Russian Government... The financing under the programme in question will exceed 13 trillion rubles. 4.7 trillion rubles of them will be provided from the federal budget. Over 17,000 kilometres of federal, regional and local motor roads, over 100 airport runways will be constructed. The total annual throughput capacity of sea ports will increase by over 400 million tons of cargo. Over 3,000 kilometres of new railways will be commissioned.*

Vladimir Putin, Russian Prime Minister, May 20, 2008, Sochi

### 1. Background and motivation

‘Connective infrastructure’ has been widely used to physically integrate regions within countries. By reducing the costs imposed by distance, policymakers believe that investment in connective infrastructure can reduce development gaps between peripheral and leading regions of their countries. In principle, infrastructure investment that connects peripheral areas to markets should improve both consumer welfare and productive efficiency. But has it stimulated growth in peripheral regions? And as countries relax regulations on where firms can locate production as they become globally integrated, is this investment favouring spatial equity at odds with overall national economic prospects? We examine these questions for Russia, a country that is wrestling with the legacy of institutions that were historically set up to ensure internal convergence through investment supporting spatial balance in the distribution of people and jobs across the national territory.

Lessons from the Russian example can provide insights for Central and Eastern European countries facing similar challenges of balancing spatial equity and national economic efficiency. In this study we focus on the potential consequences of road-infrastructure improvements, which are high on the current economic-policy agenda in Russia. A related analytical consideration is that we can use information on road conditions to develop indicators of market access, thus making it possible to empirically test hypotheses from the new economic geography literature.<sup>1</sup>

Our empirical assessment of the questions raised above is based on employing data at the firm level, which come from the Russian Enterprise Registry Longitudinal Database, a database of all large and medium-sized and many small industrial enterprises covering mining, manufacturing, and utilities. Cross sections of these firms are available from 1985-2004.<sup>2</sup> We geo-reference each firm down to the third level of Russian administrative units - *raions* - thereby making these data usable for spatial

1 One of the key insights from this literature is that spatial concentration of economic activity increases with improvements in infrastructure links between peripheral and leading regions. This is because firms are attracted to locations with high market potential and low production costs.

2 The data include basic indicators on all enterprises (such as employment, output, capital, and location) and product data at the ten-digit level for most enterprises.



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analysis.<sup>3</sup> The most appealing feature of this geo-referenced dataset is that we can observe the spatial distribution of firms in two different economic environments – pre-transition, when central planners decided where firms should be located and what they should produce; and post-transition, when private entrepreneurs had more say in locating firms in places where they could maximize return on investment.

This distinction allows us to test our first hypothesis that firms are likely to locate closer to markets as countries liberalize their economic policies. Evidence for China and India tends to support this hypothesis.<sup>4</sup> For Russia there is evidence that Soviet location policies concerned with spatial equity not only ignored transportation costs but also did not account for the costs associated with the country's cold climate. Gaddy (2008) argues that by being placed in some of Russia's coldest and most remote regions, many manufacturing enterprises were not competitive and, hence, were less attractive for foreign investment.

**Remoteness from markets impinges on productivity and has firms produce a larger-than-optimal number of products.**

Our second hypothesis is that remoteness from markets has impinged on firm productivity. To examine the cost of remoteness, we identify econometrically if geographic factors such as market access, proximity to Moscow, access to railroads and ports, and winter temperatures are systematically associated with differences in productivity. An added cost of remoteness is that firms are likely to adapt by producing a larger number of heterogeneous products at any given location in order to insure themselves against supply-chain and logistic breakdowns.

However, the origins of this peculiarity are not distance related but politically motivated. In Soviet times, ministers wanted control over production and vertically integrated their ministries by building intermediate-goods enterprises outside of their assigned line of production. One of our interests is in examining if vertical integration at the level of the production unit led to productivity losses from limited specialization. All else being equal, one would expect to see a larger number of unrelated products made by firms in peripheral regions.

To implement this analysis, we develop a measure of market access based on the classic gravity model commonly used in the analysis of trade between regions and countries. Interaction between two places is proportional to the size of the two places as measured by population, employment or some other index of social or economic activity, and inversely proportional to distance – physical or economic – between them. In addition, we use a Geographic Information System (GIS) to develop spatially detailed variables on natural and economic geography.

Our main findings from this analysis are as follows. First, there has been a clear shift in industry location towards places with good market access. Indeed, our data show that between 1989 and 2004, 70 percent of the national increase in firms happens in regions which are above the 80<sup>th</sup> percentile of market access, in contrast to only 4 percent for regions below the 20<sup>th</sup> percentile. Second, market access has a positive and significant impact on productivity – this effect is particularly strong for private firms (relative to publicly-owned ones), new firms (relative to older ones), and for manufacturing firms (compared with mining firms). We also find that producing a larger number of unrelated products is harmful for productivity.

<sup>3</sup> In our classification, *raions* include so-called *gorsovets*. There are approximately 2400 *raions/gorsovets* in Russia.

<sup>4</sup> In China, after the implementation of an open-door policy in 1978, foreign firms preferred to locate in cities such as Shanghai and Shenzhen with large industrial bases and historical foreign investment presence (Head and Ries 1996). In India, once industrial regulations were relaxed, private investment tended to favour existing industrial clusters and metropolitan centers with access to the coast (Lall and Chakravorty 2005).

What are the implications of these findings for the spatial allocation of infrastructure improvements? The results from the empirical exercise are used to simulate where improving transport infrastructure will produce the highest gains in productivity. By improving infrastructure endowments across regions by the same magnitude, we find that the returns in terms of productivity gains are the highest in the Central region around Moscow, the country's leading region. On the other hand, transport improvements produce lower returns in peripheral regions – particularly in the Far Eastern region. Thus, infrastructure by itself will not be adequate to bring about economic convergence across regions, and spatially equitable infrastructure policies may be accompanied by a trade-off with national economic performance.

The rest of this paper is organized as follows: Section 2 discusses the development of the market-access measure and related geographic variables. Section 3 discusses the spatial evolution of economic activity in Russia. Section 4 provides the estimation strategy and discusses the geographic determinants of productivity differences. Section 5 provides a policy simulation to examine the economic consequences of alternate spatial configurations of transport improvements. Section 6 concludes.

## 2. Indicators of market access

### 2.1 Selection of the measure

Access to markets is a function of geographic heterogeneity and space, and is also a function of the quality and speed of infrastructure connections. In this sense, 'accessibility' is both a function of natural geography and an outcome of the transportation system, both of which determine the locational advantage of a region relative to all regions. To assess the degree of accessibility of markets and population agglomerations, economists and economic geographers have formulated indicators of relative accessibility according to which locations can be ranked. These indicators of accessibility measure the benefits households and firms in a region enjoy both from the infrastructure they have access to and the travel costs imposed by the exogenous geographic conditions they face. As such, they are a measure of relative potential accessibility of markets or agglomerations.<sup>5</sup>

*Market accessibility is a function of natural geography and the transportation system.*

An early and well-known formulation of such an indicator is the Harris (1954) market-potential equation, widely used in regional economics. Using distance data for the US and the value of retail sales per US county, Harris found that the market potential of any location could be described by:

$$(1) \quad MP_i = \sum_{j=1}^R \left( \frac{M_j}{D_{ij}} \right)$$

where  $MP_i$  is the market potential of location  $i$ ,  $M_j$  is the demand by location  $j$  for goods from location  $i$ , and  $D_{ij}$  is the distance between locations  $i$  and  $j$ . The formulation thus provides an indication of the general proximity of a location to total demand, and was found to accurately predict the relative spatial distribution of the size of markets in US counties studied by Harris.

Since that time, many measures of relative market accessibility have been formulated, including those that can be defined to reflect both within-region transport infrastructure and infrastructure outside the region but affecting it. Simple indicators of relative intraregional transport infrastructure

<sup>5</sup> In this study, we use market accessibility and market potential interchangeably.

are, for example, total length of motorways, number of railway stations (Biehl 1986 and 1991) or travel time to the nearest nodes of interregional networks (Lutter *et al.* 1993). More complex indicators take into account the connectivity of transport networks by distinguishing between the network itself (*i.e.*, nodes and links) and ‘opportunities’ represented by large markets that can be reached by the network (Bökemann 1982). In more general terms, accessibility is a construct of two functions, one representing the opportunities or markets to be reached, and the other representing the effort, distance, time or – more specifically in economic terms – the cost of reaching them:

$$(2) \quad A_i = \sum_j g(W_j) f(c_{ij})$$

**Market accessibility is the accumulated total of economic activity in all regions weighted by the cost of getting to each region.**

where  $A_i$  is the accessibility of region  $i$ ,  $W_j$  is the activity to be reached in region  $j$ , and  $c_{ij}$  is the generalized cost of reaching region  $j$  from region  $i$ . The functions  $g(W_j)$  and  $f(c_{ij})$  are called the *activity functions* and *impedance functions*, respectively. They are associated multiplicatively (*i.e.*, they are weights to each other) and are both necessary elements of ‘accessibility’.  $A_i$  is the accumulated total of the activities reachable at  $j$  weighted by the cost of getting from  $i$  to  $j$ . Furthermore, the formulation captures a gravity model of economic potential building on Newton’s law of gravitation, which specifies that the attraction of a distant body is equal to its mass weighted by a decreasing function of distance. Here the attractors are the economic activities or opportunities in regions  $j$  and the distance term is the impedance  $c_{ij}$ . The interpretation is thus the greater the number of attractive destinations in regions  $j$ , and the more accessible regions  $j$  are from region  $i$ , the greater is the accessibility of region  $i$ .

The activity function may be linear or non-linear, but empirical sensitivity testing in the literature tends to favour a non-linear function as better capturing actual spatial economic distributions: Specifically, a negative exponential function is used, in which a large  $\beta$  parameter indicates that nearby destinations are given greater weight than remote ones:

$$(3) \quad A_i = \sum_j W_j \exp(-\beta c_{ij})$$

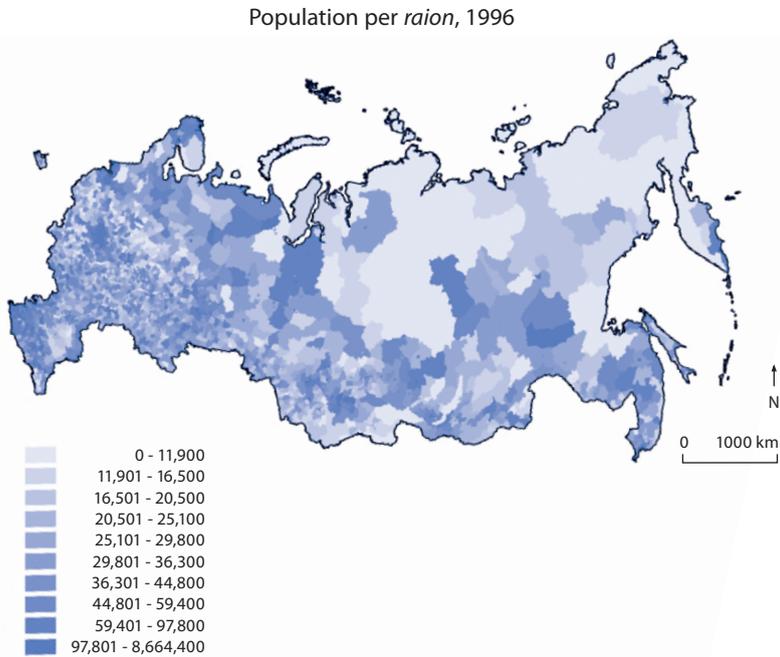
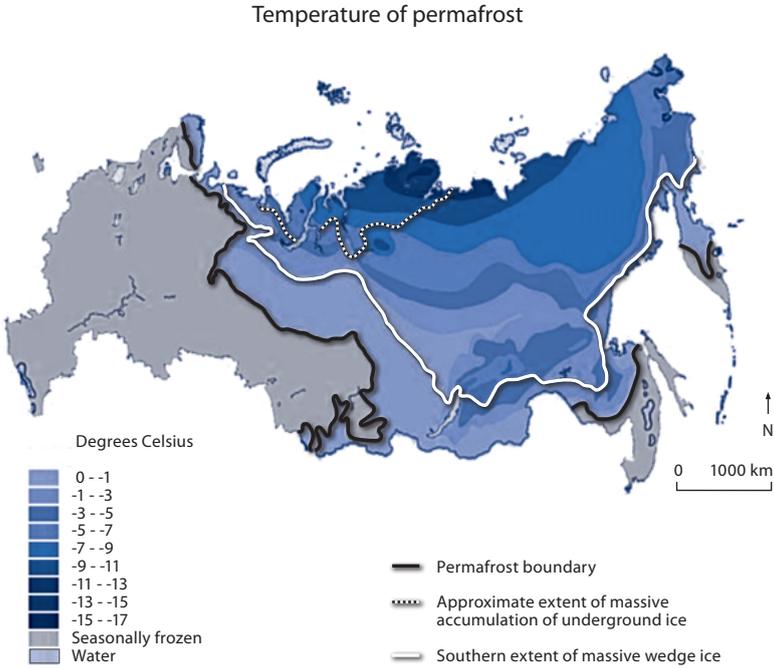
## 2.2 Construction of potential accessibility indices for Russia

**Level of analysis.** Measures of accessibility are calculated for all Russian *raions* for three time periods (1989, 1995 and 2002) using Equation (3) above. In Russia, *raions* (*i.e.*, ‘districts’), constitute the third level of administrative districts, one below the level of regions (*oblasts*). There are approximately 2400 *raions* (including so-called *gorsovet*s) across all of Russia, and overall they have changed little since 1989, providing for spatial continuity over time.

**Calculating accessibility in the GIS.** Aggregate *raion* population, obtained from the 1989 and 2002 Russian censuses and from government statistical data for 1995 (Gosudarstvennyi 1995; Tsentralnaya 1996), is used as the measure of ‘attractiveness’ in the accessibility calculations (*i.e.*, for the  $W$  term in Equation (3) above).<sup>6</sup> Figure 1 shows the distribution of inhabitants by *raion* along with a map of permafrost temperatures – showing that Soviet planning left many people in very cold places.

<sup>6</sup> We use population as a proxy for market size as we do not have data on GDP or income at the *raion* level.

Figure 1. Russian climate and population distribution



Source: Permafrost map: National Snow and Ice Data Center (2008); population map: Own calculations based on Gosudarstvennyi (1995) and Tsentralnaya (1996)

For the impedance function *c* in Equation (3), travel time through road networks, weighted by variation in road type and quality, and by topographic variation, is calculated using a GIS and

**Actual travel routes to markets are longer than those suggested by Euclidean distances.**

methods outlined in Farrow and Nelson (2001).<sup>7</sup> Using high-quality Russian road data (from the ADC WorldMap Roads data layers in GIS vector format) and a digital elevation model for Russia, it becomes possible to calculate travel times between any two locations. Information on road availability and quality is preferred to measures of straight-line or 'Euclidean' distance because it is a better reflection of the likely routes and travel times by which goods and people move in Russia. As the distribution of roads in Russia is not spatially uniform or complete, goods are moved from more remote regions (such as in the northeast) to the large urban markets in the west through road networks that tend to be located in the southern half of the country. Thus, travel routes to markets are likely to be much longer in practice than what Euclidean distances would suggest.

Figure 2 shows the road network used for the travel-time estimations. It illustrates that Russia has a sparse transport network. As a result, many shipping routes are not direct but involve more circuitous routes across larger primary and secondary roads that are selected to minimize travel costs and travel times to the final destination. The GIS travel-time algorithm selects a travel route in the same way as shippers in Russia choose their shipping routes: By finding the 'least-cost path' (or 'shortest-path-first' route, following Dijkstra 1959). That is, the GIS algorithm considers all possible routes through the road network that could be taken from one destination to another, and then selects the path that minimizes travel time. The calculation considers variations in road quality and topographic slope for each segment of the road network.

**Figure 2. Russian road network**



Source: VMAP0 (2008)

**Calculating final accessibility.** To compute the final accessibility measures for each *raion*, data on the population of each *raion* are taken from the censuses and used in Equation (3) as the  $W$  term.<sup>8</sup>

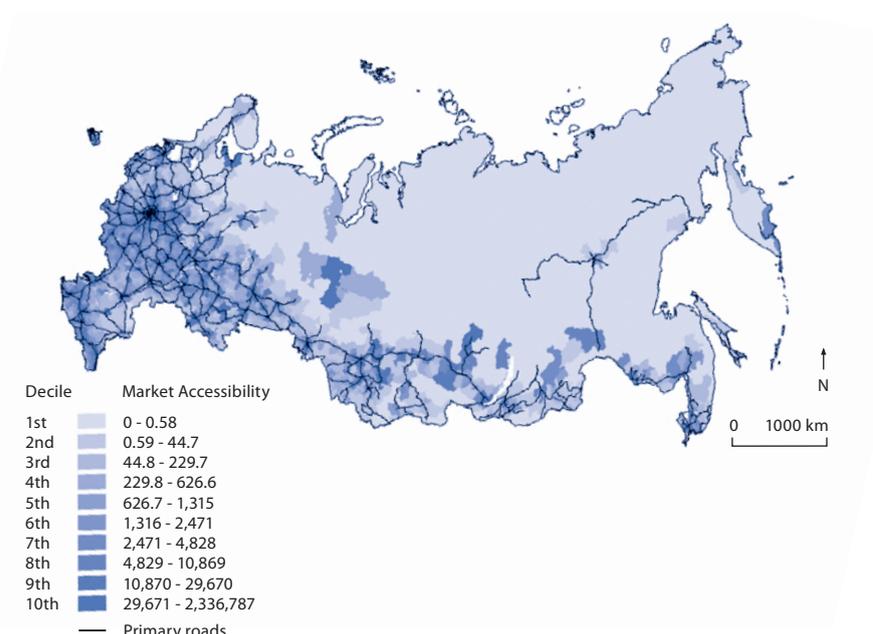
<sup>7</sup> Schürmann and Talaat (2000) and Spiekermann and Wegener (2007) provide an in-depth discussion of the algorithms behind these calculations.

<sup>8</sup> In addition to Russian *raions*, our measure of  $W$  includes population data for administrative districts of countries geographically bordering Russia to control for 'edge effects' in the accessibility calculations. These include district-level populations for Kazakhstan, Georgia, Azerbaijan, Armenia, Ukraine, Belarus, Latvia, and Estonia; 2003 NUTS3 population values for Finland; and 2002 population values for Chinese counties. Thus, it is not surprising that the *raions* on the southern border of Russia close to China have high 'potential' accessibility because there are 100 million people just south of them in China, even though we include a two-hour border crossing delay on all road segments crossing the border.

**The choice of the distance-decay parameter is an empirical decision.**

The travel times calculated by the GIS (as described above) are used as the impedance term  $c$  entering the calculation of relative accessibility for each *raion*. As market accessibility is a theoretical notion, there is no general agreement on the choice of the parameter values in Equation (3) (Deichmann 1997). The choice of parameters for  $\beta$  is ultimately an empirical decision. We calculate accessibility using five different values of the  $\beta$  parameter in the equation: 0.1, 0.25, 0.5, 1, and 1.5. The larger the  $\beta$  value, the greater weight is given to nearby destinations in the negative exponential distance-decay function. The results reported here use a  $\beta$  value of 0.5, which provides for the best empirical productivity-accessibility link. Figure 3 shows the resulting market access across Russia's regions.

**Figure 3. Potential market access across Russian regions**



Source: Own calculations of market access

Notes: The calculation method follows Schürmann and Talaat (2000) and Wilson (1967). The  $\beta$  value is 0.5, the  $a$  value is 0.1, and  $W$  corresponds to 2002 population per *raion*. The impedance function is travel times through road networks considering variation in road type/travel speed with negative exponential distance decay as a function of spatial access to population. The accessibility calculation takes populations in bordering countries into account, assuming border-crossing time to be equal to two hours.

### 3. Spatial transformation: Firms move closer to markets

Using the market access measure discussed above, we group Russia's territory into deciles of market access at the *raion* level and summarize other natural and economic geography variables (Table 1). What is striking is that over 50 percent of Russia's land is 'unconnected' in the sense of falling into the bottom decile of market access; and that part is penalized by every imaginable geographic indicator: 50 percent of the land in that decile is under permanent frost, winter temperatures are -21 degrees Celsius, and it takes more than 27 hours to reach Moscow, 54 hours to the Trans-Siberian railroad and 35 hours to a port. All these indicators improve as one gets closer to areas with good market access.

**Table 1. Russia's natural and economic geography**

| Market-access deciles in 2002 | Land area, share of national total, percent | Winter temperature, in degrees Celsius | Share of area under perma-frost | Travel time to Moscow, hours | Travel time to Trans-Siberian railway, hours | Travel time to a port, hours | Travel time to a coal deposit, hours |
|-------------------------------|---|--|---------------------------------|------------------------------|--|------------------------------|--------------------------------------|
| 1 (low)                       | 52.6  | -21.2                                  | 50.3                            | 27.9                         | 53.9   | 34.5                         | 16.0                                 |
| 2                             | 15.1  | -15.4                                  | 16.7                            | 22.6                         | 16.3   | 30.0                         | 12.1                                 |
| 3                             | 8.7   | -13.6                                  | 11.8                            | 21.1                         | 9.1  | 26.8                         | 7.7                                  |
| 4                             | 6.4   | -12.4                                  | 8.6                             | 18.5                         | 8.5  | 26.0                         | 9.4                                  |
| 5                             | 5.0   | -11.2                                  | 6.8                             | 15.8                         | 7.8  | 22.1                         | 6.5                                  |
| 6                             | 2.8   | -10.5                                  | 5.1                             | 14.7                         | 5.7  | 21.3                         | 7.2                                  |
| 7                             | 3.2   | -9.9                                   | 5.1                             | 15.1                         | 6.3  | 20.5                         | 6.5                                  |
| 8                             | 2.5   | -8.5                                   | 4.3                             | 14.6                         | 9.2  | 18.2                         | 7.1                                  |
| 9                             | 1.8   | -9.2                                   | 4.0                             | 15.2                         | 8.2  | 19.8                         | 6.2                                  |
| 10 (high)                     | 1.9   | -8.9                                   | 4.5                             | 12.3                         | 7.4  | 18.3                         | 7.8                                  |
| <b>Average/Total</b>          | <b>100.0</b>                                | <b>-12.1</b>                           | <b>11.7</b>                     | <b>17.8</b>                  | <b>13.2</b>                                  | <b>23.8</b>                  | <b>8.7</b>                           |

Note: Winter temperature data are from the WorldClim global climate layers. Travel times to Moscow, the Trans-Siberian railroad, and a coal deposit (from the USGS MRDS) are computed using the same algorithm as the accessibility calculation. Travel time to a port is from the World Bank's internal database.

**When Russia moved to a market-based economy, many firms left remote areas and new firms entered in places close to large markets.**

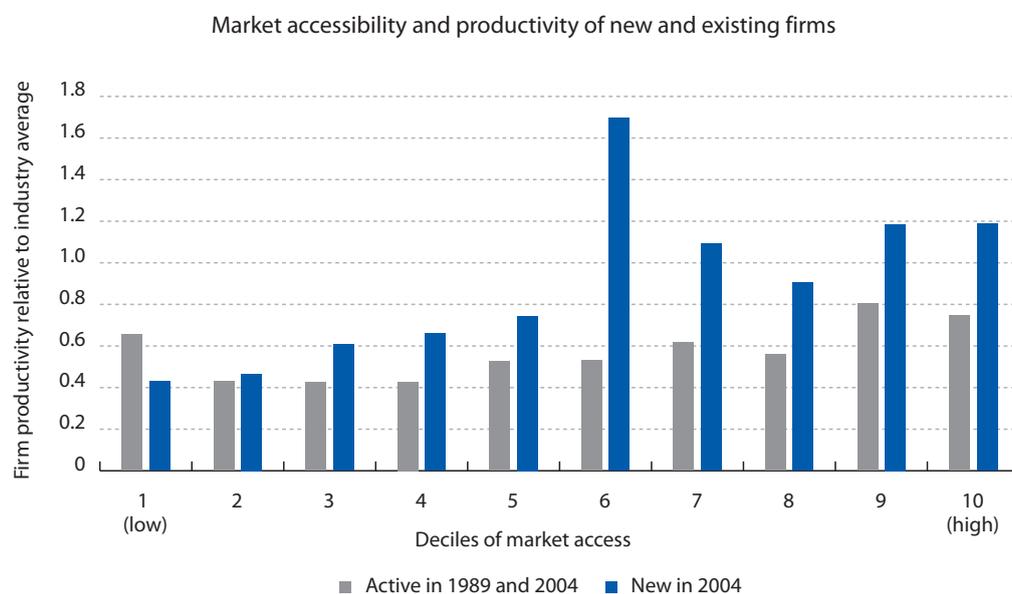
Table 2 shows that once Russia moved from a centrally-planned to a market-based economy, many firms left unconnected places and new firms entered in places physically closer to markets. Using firm-level data, we find that between 1989 and 2004, there were 266 more firms in the two lowest deciles of market access compared to about 4450 in regions in the top-two deciles. Put another way, 70 percent of the national increase in firms has happened in regions that are above the 80<sup>th</sup> percentile of market access although these regions were host to just 47 percent of all firms in 1989. And only 4 percent of the national increase in firms has taken place in regions in the two bottom deciles – clearly below the share of firms these regions were hosting in 1989 (7 percent).

**Table 2. Number of firms by market-access deciles in 2002**

| Market-access deciles in 2002 | Average market access measures in 2002 | Number of firms in 1989 (a) | Number of firms in 2004 (b) | Change in number of firms (b-a) |
|-------------------------------|--|-----------------------------|-----------------------------|---------------------------------|
| 1 (low)                       | 8.0                                    | 383                         | 577                         | 194                             |
| 2                             | 17.2                                   | 705                         | 777                         | 72                              |
| 3                             | 24.9                                   | 896                         | 928                         | 32                              |
| 4                             | 32.7                                   | 888                         | 980                         | 92                              |
| 5                             | 43.3                                   | 1075                        | 1209                        | 134                             |
| 6                             | 57.4                                   | 1151                        | 1344                        | 193                             |
| 7                             | 77.1                                   | 1430                        | 1815                        | 385                             |
| 8                             | 109.9                                  | 1706                        | 2485                        | 779                             |
| 9                             | 183.7                                  | 2127                        | 3446                        | 1319                            |
| 10 (high)                     | 811.7                                  | 5136                        | 8253                        | 3117                            |
| <b>Average/total</b>          | <b>136.6</b>                           | <b>15497</b>                | <b>21814</b>                | <b>6317</b>                     |

Figure 4 shows that new firms have not only located closer to markets but that they also have higher productivity. Clearly, economic distances are shrinking as firms move physically closer to markets.

**Figure 4. New firms are entering closer to markets, with higher productivity**



Finally, Tables 3 and 4 describe how firm entry and exit are correlated with market access. Table 3 shows that new firms are more productive than old firms (established before 1989), and firms become less productive compared with their concurrent rival firms. The last two columns of Table 4 show that firms in areas with high market access have higher survival rates than firms in low-market-access areas. Combining these facts, we conclude that Russian firm productivity growth and corresponding national economic growth would benefit more from promoting entrepreneurship and new firm creation particularly in high-market-access areas than from subsidizing old and unproductive firms.

***National economic growth would benefit more from new firm creation than from subsidizing old and unproductive firms.***

**Table 3. Productivity of entering and exiting firms**

| Firm entry and exit                           | Firm productivity relative to industrial average at 2-digit NACE level |      |      |
|---|--|------|------|
|   | 1989   | 2001 | 2004 |
| Active in 1989 but exited before 2004         | 0.99   | 0.63 |      |
| Active in 1989 and 2004                       | 1.02   | 1.06 | 0.68 |
| New and active in 2001 but exited before 2004 |  | 0.90 |      |
| New and active in 2001 and 2004               |  | 1.18 | 0.79 |
| New and active in 2004                        |  |      | 1.38 |

**Table 4. Firm entry and exit by market-access deciles**

| Market-access deciles in 2002 | Number of firms                        |                         |  |                                 |                        | Survival rate of firms in 1989<br>b/(a+b), percent | Survival rate of new firms in 2001<br>d/(c+d), percent |
|-------------------------------|--|-------------------------|--|---------------------------------|------------------------|--|--|
|                               | Active in 1989, but exited before 2004 | Active in 1989 and 2004 | New and active in 2001, but exited before 2004 | New and active in 2001 and 2004 | New and active in 2004 |  |  |
|                               | (a)                                    | (b)                     | (c)  | (d)                             |                        |  |  |
| 1 (low)                       | 239                                    | 99                      | 123  | 174                             | 334                    | 29.3   | 58.6   |
| 2                             | 440                                    | 179                     | 185  | 257                             | 427                    | 28.9   | 58.1   |
| 3                             | 548                                    | 232                     | 214  | 278                             | 486                    | 29.7   | 56.5   |
| 4                             | 467                                    | 329                     | 213  | 267                             | 442                    | 41.3   | 55.6   |
| 5                             | 600                                    | 342                     | 241  | 340                             | 543                    | 36.3   | 58.5   |
| 6                             | 599                                    | 425                     | 258  | 405                             | 516                    | 41.5   | 61.1   |
| 7                             | 700                                    | 564                     | 321  | 539                             | 736                    | 44.6   | 62.7   |
| 8                             | 783                                    | 692                     | 407  | 758                             | 1034                   | 46.9   | 65.1   |
| 9                             | 976                                    | 827                     | 477  | 1053                            | 1493                   | 45.9   | 68.8   |
| 10 (high)                     | 2051                                   | 2202                    | 1075   | 2177                            | 3497                   | 51.8   | 66.9   |
| <b>Total</b>                  | <b>7403</b>                            | <b>5891</b>             | <b>3514</b>                                    | <b>6248</b>                     | <b>9508</b>            | <b>44.3</b>  | <b>64.0</b>  |

*We are measuring the productivity gains from proximity to markets and access to transport infrastructure.*

To sum up, the maps and descriptive statistics indicate that economic activity is moving closer to markets following transition and that this move is associated with improved economic performance. Our main interest is in measuring the gains in productivity due to proximity to markets and access to network infrastructure, and in thereby assessing the costs in terms of lost productivity due to central-planning decisions of spreading economic activity across the Russian territory.

#### 4. Geographic determinants of productivity differences

In this section, we discuss the econometric analysis to examine the drivers of productivity at the firm level. The underlying economic model is that firms try to maximize their profits by optimizing and adjusting their production systems to the local environments in which they are operating. Local market conditions both on the supply and the demand sides, access to external markets, and natural environments, in particular winter temperature in Russia, influence firm behaviour and performance. We examine what kinds of location-specific endowments influence firm performance, specifically productivity.

We first measure firm productivity as Solow residuals from a simple Cobb-Douglas production function. The firm-level production function is estimated by regressing the value of production on the average number of employees and the book value of fixed assets (capital stock) separately for 19 two-digit NACE industries. The nominal values in each year are converted to 2001 prices using implicit deflators, which are disaggregated for about 150 industry sectors.<sup>9</sup>

##### 4.1 Too many products?

Before analyzing the spatial determinants of productivity, we explore an important factor that we believe is likely to influence productivity – that is, vertical integration or the number of product lines that a firm engages in. Why is this important in Russia? Because in Soviet times, ministers

<sup>9</sup> Implicit deflators are calculated by taking the change in nominal value of production of the sector divided by the real change (what Rosstat calls the index of growth in production), using sectoral growth numbers produced by Rosstat.

wanted control over production and vertically integrated their ministries by building intermediate goods enterprises outside of their assigned line of production. Following privatization, Russian oligarchs have also used vertical integration to their advantage as they want to ensure that there are no hold-ups in production in markets with few buyers and sellers (Guriyev and Rachinsky 2005).<sup>10</sup> Even though this approach helps firms adapt to local conditions and internalize various binding constraints, it is likely to introduce inefficiencies in resource allocation, thereby hurting productivity. These history-related inefficiencies are explicitly taken into account as an additional supply-side variable in the analysis of firm productivity below. Yet as the number of product lines of a firm and its productivity are likely to be at least partly driven by the same determinants (notably natural geography and infrastructure endowments), the number of product lines cannot enter the productivity regressions directly due to potential multicollinearity problems. Rather, the empirical strategy consists in estimating the determinants of the number of product lines in an auxiliary regression and in using the residuals, which capture the non-spatial component of vertical integration, in the main productivity regressions presented in Sub-section 4.2.

For a start, it is useful to understand the structure of the firm data. Typically, an establishment is defined as each part of a firm that has a different physical location – and all production in one physical location is considered as one establishment. However, in Russia and other parts of the former Soviet Union, firms usually located all their production in one geographical location. These single-location firms were often quite large and comprised several production units, similar to multi-establishment firms in market economies such as the United States (Brown and Brown 1999).

In many countries, individual establishments have become more specialized over time whereas firms have diversified. In Russia, however, even establishments are becoming more diverse. Comparing production structures in the United States and in Russia, Brown and Brown (1999) show that 88 percent of Russian establishments were producing multiple products in 1997, accounting for 97 percent of total industrial output. In contrast, only 30 percent of the US establishments were multi-product, with 66 percent of total output in 1982.

To examine if vertical integration has a spatial dimension, we econometrically analyze the effects of geographic conditions on the number of product lines by firm.

$$(4) \quad \text{Number of product lines}_{ij} = f(MP_j, Aggre_j, \text{travel time}_j, \text{winter temperature}_j)$$

The number of product lines of firm  $i$  in *raion*  $j$  is regressed on the *raion's* market potential ( $MP_j$ ), agglomeration economies ( $Aggre_j$ ), access to external markets ( $\text{travel time}_j$ ), and natural constraints ( $\text{winter temperature}_j$ ). Our measure of market accessibility developed in Section 2 accounts for market 'demand' for a firm's products. It directly tests the propositions in the new economic geography literature that regions with larger market demand attract a disproportionate share of economic activity (Krugman 1991).

The variable  $Aggre_j$  measures agglomeration economies as the number of firms in the region (*raion* in this case). The co-location of firms generates positive externalities that enhance productivity of all firms in the region. These externalities can occur within a given industry and between inter-related industries (Marshall 1890), but also across diverse industries in the same region (Jacobs 1969). Within the same industry, these benefits include sharing of sector-specific inputs, skilled labour, knowledge, intra-industry linkages, and opportunities for efficient subcontracting. Across industries, externalities include innovation and knowledge sharing. In a review of agglomeration

<sup>10</sup> For example, they report that all major Russian oil companies are vertically integrated; most steelmakers own sources of coal and ore; and some companies own ports, fleets of railroad cars and even rail tracks.

**Vertical integration  
at the firm level is  
a response to the  
constraints imposed by  
remoteness.**

measures, Henderson (2003) shows that the number of firms in a region performs better than other empirical measures.<sup>11</sup>

The results from the product-line estimations are provided in Table 5. We find that in part, vertical integration at the firm level is a response to the constraints imposed by remoteness: The number of product lines (across industrial sectors) increases as firms are further away from markets (using market access as well as distances to Moscow and a port) and when they are in cold places (low winter temperatures).

**Table 5. Determinants of the number of product lines**

|  | (1)                                   | (2)                                   |
|--|---------------------------------------|---------------------------------------|
| Dependent variable                               | Number of firm<br>product lines, 2004 | Number of firm<br>product lines, 2004 |
| Estimation method                                | GMM                                   | OLS                                   |
| Sample   | Total                                 | Total                                 |
| Ln(market access, 2002)                          | -0.096***<br>(0.034)                  | -0.066**<br>(0.034)                   |
| Ln(total number of firms in <i>raion</i> , 2004) | 0.114***<br>(0.037)                   | 0.049<br>(0.036)                      |
| Ln(winter temperature)                           | 0.333***<br>(0.072)                   | 0.348***<br>(0.085)                   |
| Ln(travel time to Trans-Siberian railway)        | -0.015<br>(0.018)                     | -0.007<br>(0.015)                     |
| Ln(travel time to Moscow)                        | 0.112***<br>(0.023)                   | 0.129***<br>(0.025)                   |
| Ln(travel time to a port)                        | 0.072*<br>(0.038)                     | 0.102***<br>(0.038)                   |
| Industry-group dummies                           | Yes                                   | Yes                                   |
| Constant   | Yes                                   | Yes                                   |
| Observations                                     | 19,555                                | 19,555                                |
| R <sup>2</sup>                                   | ..                                    | 0.094                                 |

Notes: Robust standard errors in parentheses. \*, \*\* and \*\*\* denote significance at the 10-percent, 5-percent and 1-percent levels, respectively. The estimation implements the OLS and the two-step efficient Generalized Method of Moments (GMM) estimator. Robust standard errors are in parentheses, and the observations are assumed to be independent across *raions* (no clustering) but not necessarily independent within *raions*. The instruments used in the GMM estimations are *raion*-level Ln(market potential in 1995), Ln(total number of firms in *raion*, 1989), Ln(travel time to Trans-Siberian railway, 1989), Ln(travel time to Moscow, 1989), Ln(Euclidean distance to Trans-Siberian railway), Ln(Euclidean distance to Moscow), a dummy for state capital city, share of arable lands, a dummy for permafrost region, Ln(annual temperature), Ln(annual precipitation), Ln(average elevation), Ln(standard deviation of elevation), Ln(winter temperature), and industry-group dummies for firms.

11 While in principle, market potential and agglomeration benefits represent two separate mechanisms that influence firm behaviour and performance (demand and supply, respectively), empirical applications may encounter considerable correlation between these measures. We find that the correlation between market potential and the number of firms in a *raion* is 0.7, which is high but less than 0.9, which is the rule of thumb criterion where multi-collinearity may be considered harmful. In the empirical application, due to multi-collinearity one of the coefficient estimates will become insignificant.

## 4.2 Effects of remoteness on productivity

Now we examine the cost of remoteness on firm-level multi-factor productivity (MFP) directly by regressing total factor productivity on the first- and second-nature geographic variables described above and the residual of the product-line regression as a proxy for the non-spatial component of vertical integration.

$$(5) \quad \text{Firm productivity} = f \left( \begin{array}{l} MP_j, Aggre_j, \text{travel time}_j, \text{winter temperature}_j, \\ \text{residual of Eq. (4)} \end{array} \right)$$

This estimation makes it possible to examine how remoteness impinges on productivity of Russian firms. One issue that needs to be addressed is the correlation of unobserved regional attributes with explanatory variables used in the analysis. These regional attributes influence the distribution of local market conditions and, more importantly, the location and quality of transport infrastructure. More favourable geo-climates would have attracted more people, leading to infrastructure development in their regions. This would lead to an upward bias in estimates using Ordinary Least Squares (OLS) estimators. However, in the Soviet Union, decisions to pursue spatial equity in infrastructure location may have reduced the development potential for regions with natural advantages. Here OLS estimators are likely to be downward biased. To address this problem, we estimate the model using the Generalized Method of Moments (GMM). The instruments used are historical and geo-climatic conditions.

The results and methodological details are reported in Table 6. The main findings based on the results reported in column 1 are that market access and agglomeration economies have positive effects on productivity, vertical integration and harsh geography (low winter temperatures and long distances to markets and ports) have negative effects. Consider, for example, the coefficient of 0.076 for market access in column 1. This would imply that a doubling of market access would increase firm productivity by 7.6 percent. And the coefficient of -0.08 for travel time to Moscow would imply that firm level productivity would increase by 0.8 percent for a 10 percent reduction in travel times. This could either be achieved by firms moving closer to Moscow or transport improvements that reduce the cost of Russia's large distances.

***Both a 10-percent increase in market potential and a 10-percent decrease in travel times would boost productivity by 0.8 percent.***

**Table 6. Determinants of firm productivity (MFP), by firm characteristics**

|  | (1)                  | (2)                  | (3)                  | (4)                  | (5)                           | (6)                  |
|--|----------------------|----------------------|----------------------|----------------------|-------------------------------|----------------------|
| Dependent variable                               | Ln(firm MFP, 2004)            | Ln(firm MFP, 2004)   |
| Estimation method                                | GMM                  | OLS                  | GMM                  | GMM                  | GMM                           | GMM                  |
| Sample   | Total                | Total                | Private firms        | Public firms         | Firms established before 2001 | New firms after 2001 |
| Ln(market access, 2002)                          | 0.076***<br>(0.021)  | 0.044**<br>(0.021)   | 0.102***<br>(0.024)  | 0.005<br>(0.030)     | 0.023<br>(0.021)              | 0.128***<br>(0.030)  |
| Ln(total number of firms in raion, 2004)         | 0.044*<br>(0.025)    | 0.096***<br>(0.023)  | 0.011<br>(0.028)     | 0.133***<br>(0.035)  | 0.075***<br>(0.025)           | -0.001<br>(0.035)    |
| Number of firm product lines, 2-digit NACE, 2004 | -0.049***<br>(0.005) | -0.049***<br>(0.005) | -0.039***<br>(0.005) | -0.070***<br>(0.014) | -0.034***<br>(0.005)          | -0.058***<br>(0.012) |
| Ln(winter temperature)                           | -0.910***<br>(0.124) | -0.570***<br>(0.112) | -1.131***<br>(0.153) | -0.275**<br>(0.118)  | -0.934***<br>(0.141)          | -0.696***<br>(0.135) |
| Ln(travel time to Trans-Siberian railway)        | -0.032**<br>(0.013)  | -0.014<br>(0.012)    | -0.032**<br>(0.015)  | -0.038**<br>(0.018)  | -0.034***<br>(0.013)          | -0.036*<br>(0.019)   |
| Ln(travel time to Moscow)                        | -0.080***<br>(0.014) | -0.056***<br>(0.015) | -0.091***<br>(0.015) | -0.028<br>(0.018)    | -0.097***<br>(0.014)          | -0.063***<br>(0.018) |
| Ln(travel time to a port)                        | -0.226***<br>(0.032) | -0.135***<br>(0.020) | -0.247***<br>(0.033) | -0.177***<br>(0.054) | -0.211***<br>(0.035)          | -0.226***<br>(0.040) |
| Industry-group dummies                           | Yes                  | Yes                  | Yes                  | Yes                  | Yes                           | Yes                  |
| Constant   | Yes                  | Yes                  | Yes                  | Yes                  | Yes                           | Yes                  |
| Observations                                     | 14,902               | 14,902               | 11,845               | 3,057                | 9,027                         | 5,875                |
| R <sup>2</sup>                                   | ..                   | 0.076                |                      |                      |                               |                      |

Notes: Robust standard errors in parentheses. \*, \*\* and \*\*\* denote significance at the 10-percent, 5-percent and 1-percent levels, respectively. The variable 'number of firm product lines' corresponds to the residuals of the GMM estimation of the product-line equation (see Equation (4) and Table 5). The instruments used in the GMM estimations are the same as those used in the product-line estimation reported in Table 5.

The main difference in the results for public-sector firms (column 4) is that in contrast to the results for private firms (column 3) their performance is not sensitive to market access or proximity to Moscow. However, they value proximity to ports and railroads, and they are also hurt by being located in cold places, albeit less so than private firms. Interestingly, for publicly-owned firms the number of heterogeneous products has a larger negative effect on firm productivity, and agglomeration economies at the *raion* level appear to have a stronger positive effect than for private firms. The results imply that the productivity of private firms is influenced more by market-demand conditions, whereas public-firm productivity is more linked to the supply-side factors such as agglomeration economies and vertical integration.

***The productivity of private firms depends more on demand conditions while that of public firms hinges on supply conditions.***

Columns 5 and 6 disaggregate the data based on when the firm started production. For firms in production before 2001, differences in access to markets are not associated with productivity differentials. In contrast, for firms that entered after 2001, proximity to markets is an important contributor to productivity.

Table 7 reports sector-specific regression results for mining, light manufacturing and heavy manufacturing. Let us first consider the results for light manufacturing (column 2). As expected, market access is valued by these firms – estimates suggest that productivity would be higher by 0.53 percent with every 10-percent increase in market access; and distance from Moscow, railroads and ports impinge on productivity. Also, firms in this sector value agglomeration economies – a doubling in the number of firms in the same *raion* is associated with a 5.7 percent increase in productivity. And for this sector, the number of products produced by the firm has a negative effect on productivity.

Now consider the results for heavy manufacturing in column 3. Firms in this sector are not sensitive to regional differences in market access or the strength of local agglomeration.<sup>12</sup> However, productivity of these firms is adversely affected by adverse climate and distance to infrastructure networks (connecting external markets), as well as product heterogeneity at the firm level. In contrast, the results for mining firms suggest that economic geography does not appear to influence productivity – the positive coefficient of distance from Moscow might simply reflect the fact that natural resources are located far from Moscow.

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12 This difference may come from different locations of major product markets: Local markets for light manufacturing goods and national or international markets for heavy manufacturing goods.

**Table 7. Determinants of firm productivity (MFP), by industrial sector**

|  | (1)                 | (2)                  | (3)                  |
|--|---------------------|----------------------|----------------------|
| Dependent variable   | Ln(firm MFP, 2004)  | Ln(firm MFP, 2004)   | Ln(firm MFP, 2004)   |
| Estimation method  | GMM                 | GMM                  | GMM                  |
| Sample   | Mining              | Light manuf.         | Heavy manuf.         |
| Ln(market access, 2002)                                      | 0.080<br>(0.078)    | 0.053**<br>(0.023)   | 0.042<br>(0.032)     |
| Ln(total number of firms<br>in the same <i>raion</i> , 2004) | 0.030<br>(0.077)    | 0.057**<br>(0.028)   | 0.038<br>(0.036)     |
| Number of firm product<br>lines, 2-digit NACE, 2004          | 0.015<br>(0.018)    | -0.046***<br>(0.009) | -0.058***<br>(0.007) |
| Ln(winter temperature)                                       | -0.373<br>(0.288)   | -0.624***<br>(0.110) | -1.143***<br>(0.218) |
| Ln(travel time to Trans-<br>Siberian railway)                | -0.018<br>(0.031)   | -0.037***<br>(0.014) | -0.074***<br>(0.019) |
| Ln(travel time to Moscow)                                    | 0.189***<br>(0.062) | -0.075***<br>(0.015) | -0.128***<br>(0.021) |
| Ln(travel time to a port)                                    | -0.119<br>(0.082)   | -0.227***<br>(0.036) | -0.246***<br>(0.044) |
| Industry-group dummies                                       | No                  | No                   | No                   |
| Constant   | Yes                 | Yes                  | Yes                  |
| Observations   | 723                 | 8,299                | 5,032                |

Notes: Robust standard errors in parentheses. \*, \*\* and \*\*\* denote significance at the 10-percent, 5-percent and 1-percent levels, respectively. The number of firm product lines corresponds to the residuals of the GMM estimation of the product-line equation (see Equation (4) and Table 5).

## 5. Identifying regional infrastructure priorities

Now let us return to the questions of infrastructure prioritization raised at the very beginning of this study. First, what are the implications of transport investment that improves market access of peripheral areas? And second, will this investment produce the highest economic benefits nationally – or are there trade-offs between peripheral and national growth? We use the results from the econometric analysis to simulate the impacts on firm productivity of market-access improvements across Russia's larger economic regions.

In these simulations, each region is given an exogenous increase in infrastructure endowment such as to increase market access by 10 percent and to reduce travel times to Moscow, the Trans-Siberian railroad, and a major port by 10 percent each. Given these regional infrastructure improvements, productivity growth of existing firms is computed and then aggregated to the national level. This is a conservative estimate of the impact of infrastructure improvements as some regions could also benefit from an increase in the number of firms and thereby benefit from higher agglomeration economies. However, to keep the analysis manageable, we only calculate direct effects on productivity.

The projected firm productivity improvements of these simulations are reported in Table 8 alongside relevant regional indicators such as the number of firms, population, region area, and the average market-access value. The results are then normalized to the productivity effect in the Central region, which is set equal to 100. The projected improvements in firm productivity provide the magnitude of region-level benefits from the aforementioned infrastructure improvements. Two results are worth mentioning. First, the benefits of these improvements are likely to be the highest in the Central region (which includes Moscow), followed by the North-western region (including St. Petersburg) where the productivity effect would be half that in the Central region (first column). Similar effects, ranging from one-third to 44 percent of the benchmark, are observed for most of the remaining regions. However, two regions stand out for showing particularly low economic gains: Northern and East Siberian. Second, it appears that the projected firm-productivity improvements are closely related to the economic (rather than geographic) size of regions.

*Simulations suggest that the productivity-enhancing effect of improved transport infrastructure would be by far the strongest in Russia's capital region.*

**Table 8. Simulated impact on average firm productivity growth from improving transport connectivity in different economic regions**

| 10-percent improvement of transport connectivity in the economic region of: | Projected average firm productivity growth, percent | Number of firms, 2004 | Market access, 2002 | Population, 2002 | Area, square-kilometres |
|---|---|-----------------------|---------------------|------------------|-------------------------|
| Central Black   | 0.267   | 1,471                 | 106                 | 6,285            | 158,515                 |
| North Caucasus  | 0.327   | 1,864                 | 161                 | 12,800           | 199,219                 |
| East Siberian   | 0.144   | 833                   | 54                  | 5,488            | 1,702,144               |
| Far Eastern   | 0.502   | 1,404                 | 36                  | 5,818            | 6,887,041               |
| North-western (incl. St. Petersburg)  | 0.525   | 1,733                 | 101                 | 8,957            | 311,728                 |
| <b>Central (incl. Moscow)</b>   | <b>0.998</b>  | <b>4,028</b>          | <b>428</b>          | <b>22,500</b>    | <b>255,442</b>          |
| Northern  | 0.134   | 738                   | 44                  | 3,268            | 857,748                 |
| Urals   | 0.317   | 2,156                 | 98                  | 11,500           | 558,028                 |
| Volga   | 0.401   | 2,647                 | 93                  | 15,400           | 613,472                 |
| West Siberian   | 0.369   | 2,481                 | 62                  | 10,200           | 3,193,654               |
| Volga-Vyatka  | 0.383   | 2,460                 | 90                  | 10,800           | 514,699                 |
| <b>Relative to Central, percent</b>   |   |                       |                     |                  |                         |
| Central Black   | 26.7  | 36.5                  | 24.8                | 27.9             | 62.1                    |
| North Caucasus  | 32.7  | 46.3                  | 37.6                | 56.9             | 78.0                    |
| East Siberian   | 14.5  | 20.7                  | 12.5                | 24.4             | 666.4                   |
| Far Eastern   | 50.2  | 34.9                  | 8.3                 | 25.9             | 2696.1                  |
| North-western (incl. St. Petersburg)  | 52.6  | 43.0                  | 23.7                | 39.8             | 122.0                   |
| Central (incl. Moscow)  | 100.0   | 100.0                 | 100.0               | 100.0            | 100.0                   |
| Northern  | 13.4  | 18.3                  | 10.3                | 14.5             | 335.8                   |
| Urals   | 31.7  | 53.5                  | 22.8                | 51.1             | 218.5                   |
| Volga   | 40.2  | 65.7                  | 21.8                | 68.4             | 240.2                   |
| West Siberian   | 37.0  | 61.6                  | 14.6                | 45.3             | 1250.2                  |
| Volga-Vyatka  | 38.4  | 61.1                  | 21.0                | 48.0             | 201.5                   |

Note: Technically, the improvement of transport connectivity in an economic region is simulated as a 10-percent increase in regional market access and into 10-percent decreases in regional travel times to the Trans-Siberian railway, Moscow, and the closest port, respectively.

***There is a trade-off between connecting remote regions and boosting national economic growth.***

This ranking of economic benefits has two implications. First, infrastructure investment by itself is unlikely to help growth in lagging regions and, hence, economic convergence. Second, if investment expenditure favouring spatial equity is at the expense of funding infrastructure in high-return regions such as the Central region, it is likely to impose a severe trade-off with respect to the objective of boosting national economic performance.

## 6. Conclusion

In this study, we have used firm-level data on Russian manufacturing to examine the cost of remoteness on economic productivity. By developing detailed geo-referenced indicators of market potential that account for transport infrastructure linking firms to markets, we have directly estimated the benefits that accrue to firms from locating close to dense economic regions. While central-planning decisions of distributing economic activities across space have historically impinged on productivity, new entrants are concentrating production units and locating closer to markets. This 'death of distance' has important productivity implications – our estimates suggest that a doubling of market access would increase firm productivity by 7.6 percent.

While entrepreneurs prefer to concentrate production, public policy in Russia is concerned with spatial equity. The World Bank's latest Country Economic Memorandum for Russia (World Bank 2008) shows that the growing concentration of economic activities is seen as a cause for concern. The Russian government created a Ministry for Regional Development in 2004, and a National Regional Strategy is being drafted to facilitate the adoption and coordination of policies in the area of regional and spatial development. However, the jury is still out on the extent to which the strategy should focus on supporting national growth *vis-à-vis* helping lagging regions. Our analysis provides empirical evidence to inform this discussion.

***Entrepreneurs prefer to concentrate production while public policy in Russia is concerned with spatial equity.***

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