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## Population Structures in Russia: Optimality and Dependence on Parameters of Global Evolution

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## Population Structures in Russia: Optimality and Dependence on Parameters of Global Evolution

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### **Abstract.**

The paper is devoted to analytical investigation of the division of geographical space into urban and rural areas with application to Russia. Yegorov (2005, 2006, 2009) has suggested the role of population density on economics. A city has an attractive potential based on scale economies. The optimal city size depends on the balance between its attractive potential and the cost of living that can be proxied by equilibrium land rent and commuting cost. For moderate scale effects optimal population of a city depends negatively on transport costs that are related positively with energy price index.

The optimal agricultural density of population can also be constructed. The larger is a land slot per peasant, the higher will be the output from one unit of his labour force applied to this slot. But at the same time, larger farm size results in increase of energy costs, related to land development, collecting the crop and bringing it to the market.

In the last 10 years we have observed substantial rise of both food and energy prices at the world stock markets. However, the income of farmers did not grow as fast as food price index. This can shift optimal rural population density to lower level, causing migration to cities (and we observe this tendency globally). Any change in those prices results in suboptimality of existing spatial structures.

If changes are slow, the optimal infrastructure can be adjusted by simple migration. If the shocks are high, adaptation may be impossible and shock will persist. This took place in early 1990es in the former USSR, where after transition to world price for oil in domestic markets existing spatial infrastructure became suboptimal and resulted in persistent crisis, leading to deterioration of both industry and agriculture.

Russia is the largest country but this is also its problem. Having large resource endowment per capita, it is problematic to build sufficient infrastructure. Russia has too low population density and rural density declines further due to low fertility and migration to cities. Those factors limited the growth of the USSR, but after the economic reforms of 1990s the existing infrastructure became exposed to permanent shock of high transport costs. Due to large distances it is optimal to return to gasoline and thus transport subsidy. This will work also against disintegration of the country.

**Keywords:** urban, rural, population density, prices, transport, transition.

**JEL Codes:** R14, R23, R40, R48.

## ***1. Introduction***

The world is evolving in time, with the change of population, GDP, energy consumption, price indices and other parameters. But spatial patterns are also changing: people migrate from rural to urban areas, cities grow and for some of them this growth seems to have no limit.

The first goal of this article is to investigate the influence of changes in global price indices on spatial infrastructures (city sizes and rural population density). Another goal is to explain recent changes in the population location in Russia, to explain them with this theory and to suggest policies that could improve those structures.

First, a simple model of optimal city size will be suggested. For us the explicit dependence of population size in a city on energy price is of special interest. The reason is that we observe a positive trend of energy price in the last decade. Moreover, if oil peak arrives, it will reinforce this tendency. The idea that optimal city size under oil peak should be smaller than now was already discussed in the literature; see, for example, [4]. Here this result will be obtained formally in section 2. Next, in section 3, the optimal size of small farm for self-employed peasant is studied. The result depends not only on country's territory and population, but also on price indices for food and energy. Section 4 studies equilibrium between rural and urban areas and its sensitivity to price shocks for food and energy. Section 5 describes present and future tendencies in those prices and possible reaction of spatial infrastructures on them. The case of Russia in 1990s is an important example investigated in section 6. Some policies are also suggested. Section 7 concludes.

## ***2. Model of Optimal City***

While there exist many complex models of agglomeration, this article will deal with rather simple one. It is well known that historically cities were producing industrial goods, contrary to rural areas producing agriculture. However, in the last decades services started to dominate in GDP of many countries. While they can be produced in all locations, the dominant share of services is still produced in cities. A

city of larger size is characterized with larger population and higher variety of skills. Some services (like hospital, stadium, theater) require some minimal population threshold to start their activity. Thus, a larger city will have more variety of services and thus will produce a higher service GDP per capita. There are also scale economies for infrastructure cost in a city. They bring scale economies to industrial production. Since all city economic activities (industry and services) have scale economies, there is agglomeration force working in the direction of city growth. But at the same time there exist an opposite force. It comes from general congestion. A simple way to model it is to consider central business district model (CBD). For simplicity, radial symmetric city (of radius  $R$ ) with a priori identical agents having land slots of equal size,  $b$ , is considered. Let  $H$  denotes construction cost of a basic house (that does not depend on location).

It is assumed that the price of industrial and service output is normalized to one, while the price index for energy,  $E$ , and food (agricultural output),  $A$ , can vary.

The utility of agent in a city with population  $N$  and radius  $R$  can be also viewed as city potential. It is given by the formula

$$U = BN^\epsilon - \tau R - H,$$

where  $\epsilon > 0$  is the scale factor and  $\tau(E)$  denote transport cost per unit of distance, that positively depends on energy price index,  $E$ . To make agents indifferent across locations in a city, the sum of transport costs to commute to CBD and rental price of a flat (sum of construction costs and location rent) should be constant. Assuming rental price at the edge of a city to be zero, we get that  $\tau R + H = \text{const}$ , that represent cost index to live in a city. Since the territory of radially symmetric city is  $= \pi R^2 = Nb$ , we can express  $U$  as the function of  $N$ :

$$U(N) = BN^\epsilon - \tau \left( \frac{Nb}{\pi} \right)^{\frac{1}{2}} - H.$$

The optimal city size can be obtained by differentiation; it equals to

$$N^* = \left( \frac{B\epsilon\tau^{1/2}}{\tau b^{1/2}} \right)^{1/(0.5-\epsilon)}$$

It is easy to show that the optimal city will be of finite size only for relatively small scale economies:  $\epsilon < 1/2$ .

Further we study the comparative statics. The partial derivatives of optimal city size with respect to  $b$  and  $\tau$  are both negative. The richer is population, the larger land

slot per capita,  $b$ , is demanded. This lowers optimal population of a city in developed economies.

The role of transport costs is also important. While this is not explicitly accounted, transportation time also influences utility. Technological development in transportation reduces it, and thus makes CBD accessible from larger distances; this makes city size larger. On the other hand, congestion in the form of traffic jam increases this time, and thus reduces the radius of optimal city.

Since  $\frac{dr}{dE} > 0$ , it can be concluded that the growth of energy price leads to a decrease of an optimal city size.

### 3. Equilibrium Agricultural Density

Here we focus only on the case of  $\beta < 1/2$ , where finite equilibrium city size exists. For modeling agricultural density, consider Cobb-Douglas production function in agriculture, based on labour and land. A farmer is endowed with one unit of capital and labour and applies it to land slot. If land slot is fixed, there are decreasing returns to scale to land size. At the same time, harvesting on larger land slot involves higher transport cost (see Yegorov, 2009).

Consider the following expression for a potential of a farm:

$$V_1 = AS^\nu - \tau r.$$

Let total agricultural land is normalized to one, and total population is  $N$ . Since  $S = r^2$ , we have  $\rho = N, r = \rho^{1/2}$ . The overall utility of all agricultural population is given by:

$$V_N(\rho) = NV_1(\rho) = A\rho^{1-\nu} - \tau\rho^{1/2}.$$

Differentiation gives the socially optimal population density of farmers:

$$\rho^* = \left(\frac{2A(1-\nu)}{\tau}\right)^{1/(\nu-0.5)}$$

Internal maximum exists for  $1/2 < \nu < 1$ , that is, for moderate decreasing returns to scale in land<sup>1</sup>.

Introduction of parameter  $A$  allows to study the influence of output (here food) price on agricultural infrastructure. At the same time,  $\tau$  is a proxy for energy price. If

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<sup>1</sup> This result is known in physics. Potentials of the fields with two different powers generate internal extreme. An example is the potential of Lienard-Wiechert. For different sign there will be minimum.

food price  $A$  rises, higher population density becomes optimal; more people will move to agriculture. But if energy price rises, transport cost becomes higher and optimal density will be lower.

Optimal agricultural population density depends positively on food price index and negatively on energy price index.

#### **4. Spatial Urban-Rural Structure**

Assume that all space is occupied with agricultural and urban population, but urban density is much larger, so that we can neglect the territory occupied by cities<sup>2</sup>. Let  $\square$  be the fraction of rural population,  $\rho$  - the average density and  $\rho_a$  - agricultural density. Then  $\rho_a = \gamma\rho$ . To make agents indifferent between living in a city of rural area, it is necessary to equate their utilities from both options:  $V_1 = U(N^*)$ . This leads to transcendental equation that can be reduced to cubic equation for  $y = \gamma^{1/3}$ . This equation (due to special property of signs) has a unique positive root. Thus, we can find optimal split of the population into urban and rural.

The equilibrium location structure includes "raisins" of optimal cities in a "cake" of uniformly dispersed agricultural population. For a given total population of a country, population density in cities, transport costs, coefficient of increasing returns in city and decreasing returns on agricultural land, there exists optimal number and size of cities and optimal agricultural density.

### **5. Applications**

#### **5.1. Oil Peak Influence**

The paper of Robert and Lennert (2010) analyses the impact of oil peaking for Europe. One of their results says that oil peaking will increase prices and reduce transportation, and this will restructure the whole urban system. In particular, suburbanization will be reversed and people will move to more compact cities.

In line with our model, the rise of oil prices will make energy price index higher. This will make transportation (and harvesting) more expensive. In order to keep rural areas stable, there will be an upward push to food price index. If the ratio of  $A/\square$

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<sup>2</sup> For most of the countries this is a valid assumption, since typical urban density is about 10 000 people per square km, while rural density can be as low as 1 person per sq.km but sometimes reach 100 and more.

remains constant, nothing happens with optimal rural density. That is why this shock will harm mostly urban population, who has to relocate from large to smaller cities. Since rapid construction of new smaller cities is hardly possible, in the short run there might be reverse, urban-rural migration.

## **5.2. Change in Food Price Index**

Suppose that food price index went up, but nothing happens with energy and transport prices. Then the optimal agricultural population density will grow according with the formula from section 3.

Note that this effect is predictable. If the price of one good (here food) grows, more would like to produce it. With more people in agriculture, overall output will grow, since more labour on the same land will generate it.

In a general equilibrium framework (not considered here) this output growth will reduce the price of food (in comparison with other good) and turn system to equilibrium.

The difference of spatial consideration is that it also suggests some shocks to infrastructure. Changing optimal land slots (which in fact in reassignment of land ownership) cannot be done in the short run. It may happen that in the short run farmers will be richer, while the total output will not grow since they are not willing to allow more people to agriculture as owners and workers simultaneously. However, agricultural labour might come to the sector (not in this model) and increase the production.

## **6. Russian Changes in Population Structure and Policies**

### **6.1. Russian Transition Shock**

In the former USSR transport was subsidized, since the country kept domestic price of gasoline at regulated level, below the world price. If we consider some scale economies in manufacturing that are balanced by the transport costs for the spatial area where inputs are harvested and the final good is distributed, we have mathematical model similar to one considered in the section 2. The lower this transport cost  $b$ , the larger will be the size of optimal plant  $N$ . So, if it was necessary to produce some output  $Y$  of particular good to satisfy the demand of the USSR (which was to some extent closed economy) given the price of output,  $B$  (also fixed), it was indeed optimal to build few super-giant plants, let say 10, at the distance of

about 1000 km from each other. From the formula of section 2 we can see that the capacity of one plant,  $N$ , depends positively on the ratio  $B/\lambda$ , for  $\lambda < 1/2$ .

Now it is documented, that the (inverse) price ratio  $\lambda/B$ , has increased by factor 3-4 during the transition and persistently stayed at this level thereafter<sup>3</sup>. This means that spatial industrial infrastructure was under persistent price shock. Under new conditions it would be optimal to have smaller plants with smaller market areas around. Especially this is important for cheap goods (like cement, sugar, etc) for which freight has a substantial fraction of total price. Since rebuilding of all industrial infrastructure (just to change locations and capacity) is too high investment for any country, it can be done only the very long run. Meanwhile, plants remain unprofitable. Only transport subsidy (at least partial) could have kept those industries alive, but this has not been done. The bankruptcy level in no-extracting industry in Russia in 1990s was very high. Nowadays there is neither planned investment nor transport subsidy policies to rebuild this infrastructure on new optimal level. Due to high transport costs not only interaction between regions has declined (both as trade and passenger trips) but also there was extensive rural migration to urban areas, especially in Moscow. While congestion factors in Moscow are high, the negative pushing effects from rural areas and regions dominate.

## 6.2. Too Low Rural Population Density in Russia

The difference of Russia from other countries is in its low population density (see Fig.4). This may have positive and negative effects (see Yegorov, 2009). On positive side, there is high land endowment per capita, allowing to harvest more mineral resources and to produce more agriculture. On the negative side, the population is too low to build dense road network, and still declines. This poses a persistent problem for regional and rural development in Russia.

Fig.3 shows railroad map of globe. Russia has many km of railroads, but their density even in European part is below one in Western Europe, while Siberian part has only Trans-Siberian railroad (built in 1916) with only few secondary roads without any dense network.

Another problem of Russia is relatively low land fertility. In most of its regions (apart from North Caucasus), the yield of wheat is lower than in Western Europe (see Fig. 5). While the USSR was the major global producer of wheat, Russian position

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<sup>3</sup> Presentation of A.Kauffman , ERS2013. See Fig. in Appendix.



today (as well as Ukrainian) is much lower. In 2012, Russia produced only 37.7 mln. tons of wheat and occupied the 6<sup>th</sup> position in the world<sup>4</sup>, after EU (134.5), China (125.6), India (94.9), USA (61.8) and France (40.3). Thus, Russia does not use its territory efficiently. USSR has much higher agricultural potential. Wheat was produced not only for bread, but also for feeding animals. Now Russia imports high fraction of consumed meat. Nowadays, China might require import of food in future, and this could be alternative source of income for Russia, when oil productivity will decline.

### **6.3. Disintegration of Russian Air Traffic and Threat to Integration**

The air transport was well developed in the USSR, but after its dissolution it went into decline (see Fig.2). Now most of the regions are connected only with Moscow, while in the USSR they were connected between themselves. There are two major microeconomic reasons for those changes. The first is an increase of relative transport cost in Russia after economic reforms of 1992 (see Fig.1). The second is in higher income disparity. While in the USSR the ratio of income of top 10% to bottom 10% was only 3.5 (Atkinson, Mickelwright, 1992), after transition it has grown to 15 and remains at this level for many years. Hence, air transport became non-affordable for the majority of Russian population. Demand shrinkage was especially pronounced among regions, where operation of even one air plane became non-profitable and thus was cancelled. This poses a threat to Russian regional integration.

### **6.4. Optimal Policies for Russia**

At present, Russia does not extract benefits from its large territory. It was an asset in Soviet time, but now became a liability. When all population tends to live in cities, it does not matter how large is the rural territory. For the efficient exploitation of rural resources the policy to reverse rural-urban migration should be used. Russia should use its agricultural potential more efficiently. Now it specializes on harvesting of only non-renewable resources (oil, gas, metals) but should specialize on renewable too (agriculture, forest, fishing).

One of the policies is to return to domestic subsidy of gasoline and to increase competition in transportation, making its prices well below the world level. This can also prevent Russian disintegration.

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<sup>4</sup> Source: [http://en.wikipedia.org/wiki/International\\_wheat\\_production\\_statistics](http://en.wikipedia.org/wiki/International_wheat_production_statistics)

## **7. Conclusions**

The paper has considered a simple theoretical framework based on attractive potential of a city and cost-benefit analysis of a farm) to find optimal city size and rural population density.

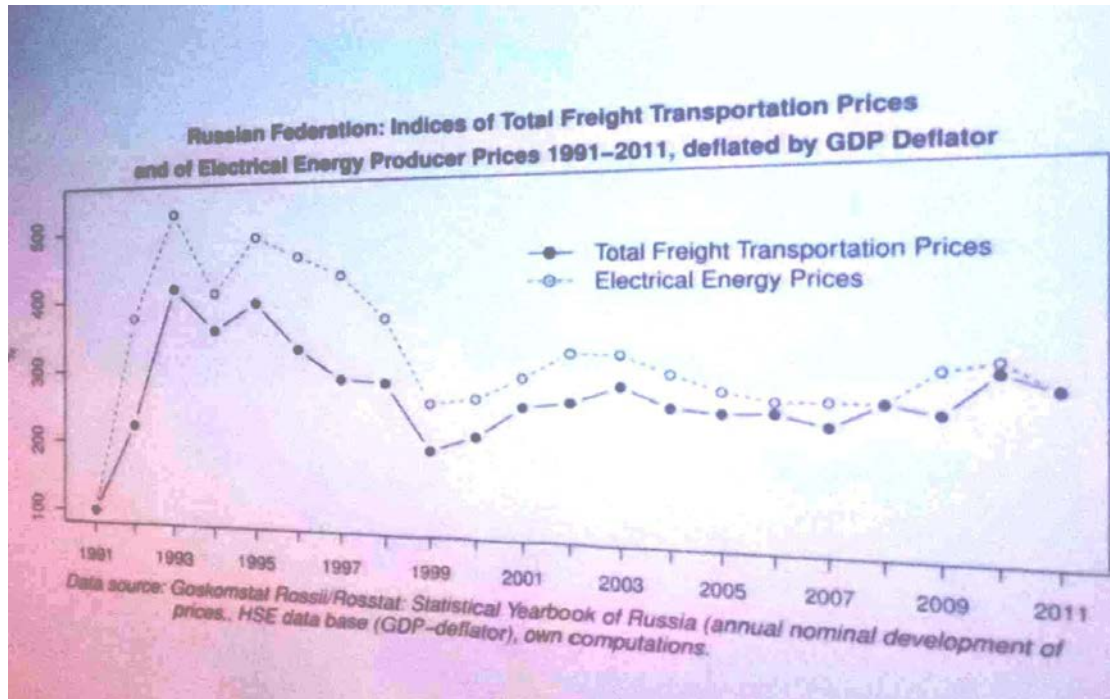
The obtained results were further analysed from the perspective of their sensitivity to external shocks in basic prices, like world food and energy price indices. It was shown that rise of energy and food price alone requires change of the whole spatial pattern, which is too costly and painful. That is why oil peak might have very negative consequences to global city network, requiring relocation and construction of new smaller cities. If food price (as return to producer) grows slower than energy prices, this causes rural shock and leads to rural-urban migration, resulting in lower rural population density that is optimal in this case.

Finally, the case of Russian transition is considered. It is a persistent shock for all industrial infrastructure that has resulted from 3-fold increase of freight cost.

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## Appendix



**Fig.1.** Change in relative transport cost in Russia after 1990.

(From presentation of Kauffmann A.)

## Текущее состояние пассажирских авиаперевозок в России

### 1. Деформация маршрутной сети:

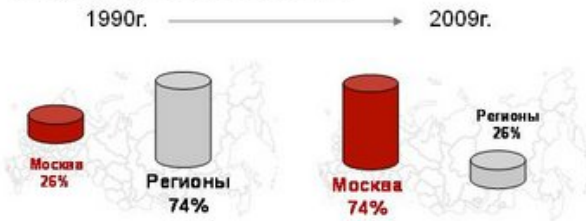
#### 1.1. СССР:



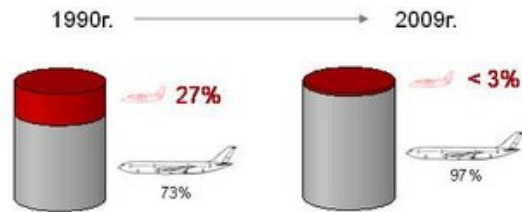
#### 1.2. Российская Федерация:



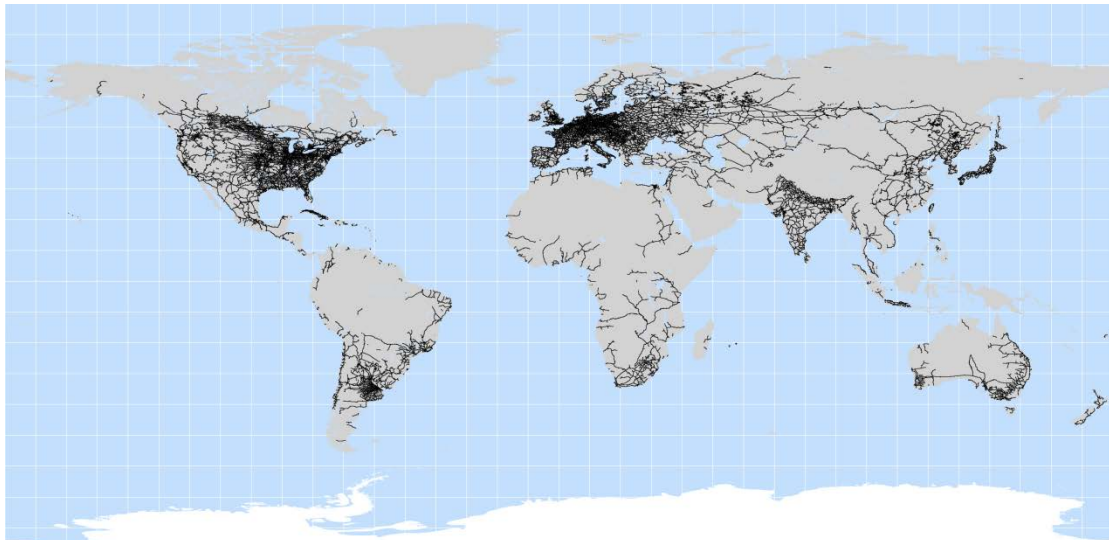
### 2. Отмирание прямых региональных связей и концентрация потоков на Москве:



### 3. Деградация местных перевозок:



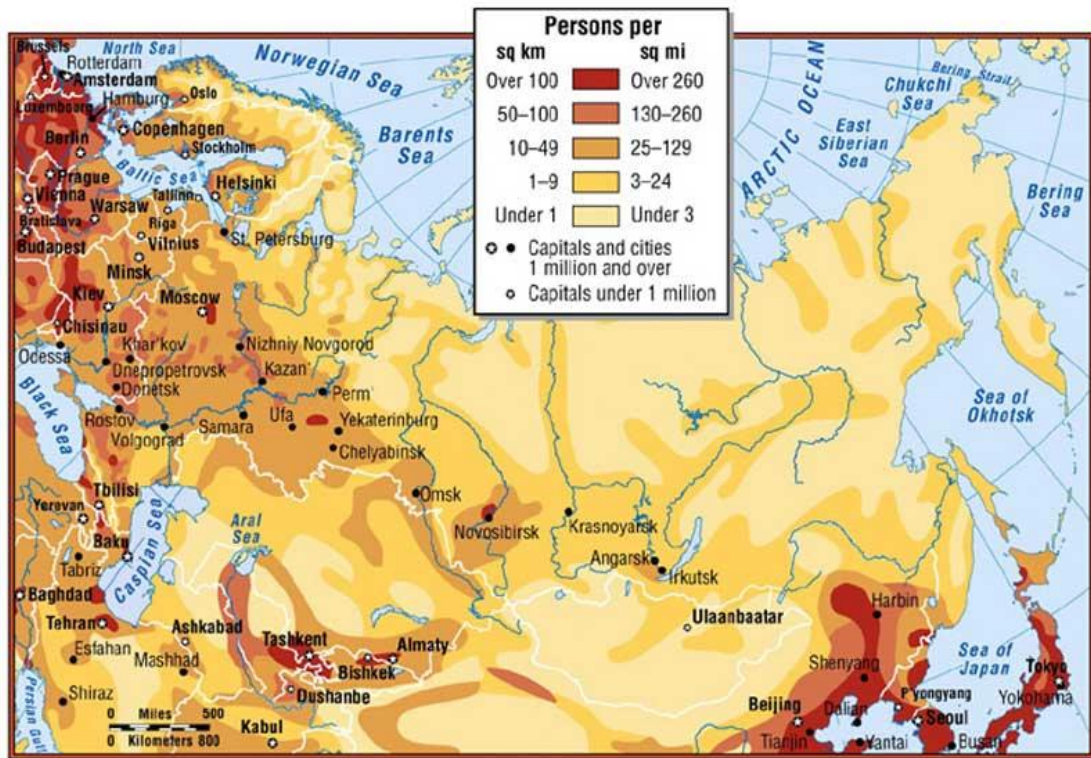
**Fig.2.** Destruction of air traffic in Russia.



**Fig.3.** Global map of railroads.

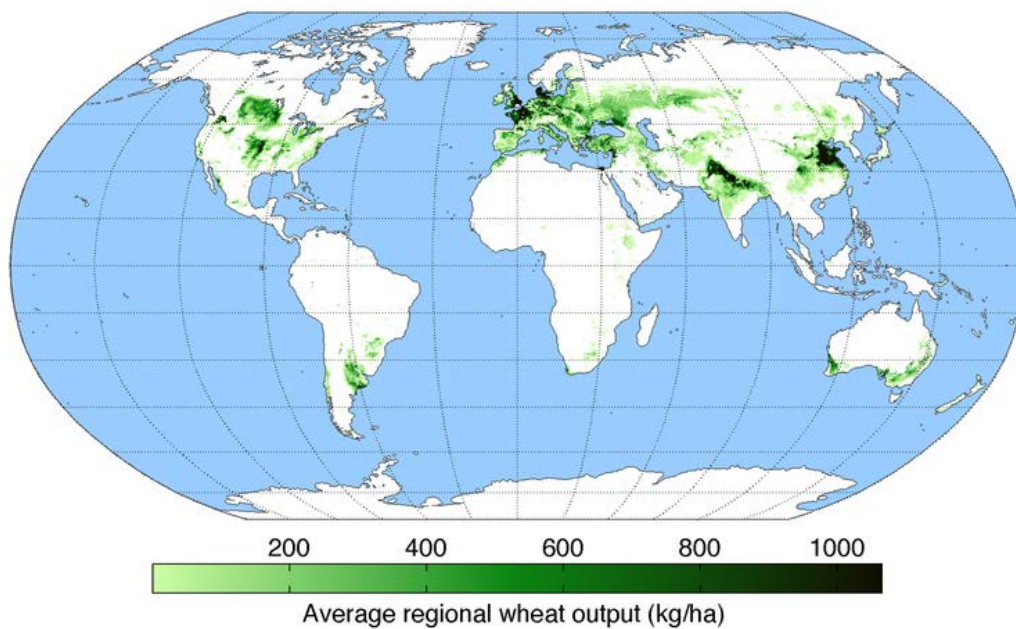
Source: <http://bioval.jrc.ec.europa.eu/products/gam/images/large/railways.png>





**Fig. 4.** Map of Russian population density.

Source: <http://www.roebuckclasses.com/maps/placemap/russia/russiipop.JPG>



**Fig. 5.** Global map of wheat yield (kg/ha).

Source: <http://en.wikipedia.org/wiki/File:WheatYield.png>