European University Institute
ROBERT SCHUMAN CENTRE FOR ADVANCED STUDIES

CARIM East – Consortium for Applied Research on International Migration

Co-financed by the European Union

Scientific Brain Drain and Human Capital Formation After the End of the Soviet Union

Ina Ganguli

CARIM-East Research Report 2013/26

Ministry of Science and Higher Education
Republic of Poland

CENTRE OF MIGRATION RESEARCH

MIGRATION POLICY CENTRE

CARIM-East
Creating an Observatory of Migration East of Europe

Research Report
CARIM-East RR 2013/26

Scientific Brain Drain and Human Capital Formation After the End of the Soviet Union

Ina Ganguli
Stockholm School of Economics (SITE)

Ina Ganguli, Scientific Brain Drain and Human Capital Formation After the End of the Soviet Union, CARIM-East RR 2013/26, Robert Schuman Centre for Advanced Studies, San Domenico di Fiesole (FI): European University Institute, 2013.

European University Institute
Badia Fiesolana
I – 50014 San Domenico di Fiesole (FI)
Italy

http://www.eui.eu/RSCAS/Publications/
http://www.carim-east.eu/publications/
http://cadmus.eui.eu

CARIM-East – Creating an Observatory East of Europe

This project which is co-financed by the European Union is the first migration observatory focused on the Eastern Neighbourhood of the European Union and covers all countries of the Eastern Partnership initiative (Belarus, Ukraine, the Republic of Moldova, Georgia, Armenia and Azerbaijan) and Russian Federation.

The project's two main themes are:

(1) migration from the region to the European Union (EU) focusing in particular on countries of emigration and transit on the EU's eastern border; and

(2) intraregional migration in the post-Soviet space.

The project started on 1 April 2011 as a joint initiative of the European University Institute (EUI), Florence, Italy (the lead institution), and the Centre of Migration Research (CMR) at the University of Warsaw, Poland (the partner institution).

CARIM researchers undertake comprehensive and policy-oriented analyses of very diverse aspects of human mobility and related labour market developments east of the EU and discuss their likely impacts on the fast evolving socio-economic fabric of the six Eastern Partners and Russia, as well as that of the European Union.

In particular, CARIM-East:

- builds a broad network of national experts from the region representing all principal disciplines focused on human migration, labour mobility and national development issues (e.g. demography, law, economics, sociology, political science).
- develops a comprehensive database to monitor migration stocks and flows in the region, relevant legislative developments and national policy initiatives;
- undertakes, jointly with researchers from the region, systematic and *ad hoc* studies of emerging migration issues at regional and national levels.
- provides opportunities for scholars from the region to participate in workshops organized by the EUI and CMR, including academic exchange opportunities for PhD candidates;
- provides forums for national and international experts to interact with policymakers and other stakeholders in the countries concerned.

Results of the above activities are made available for public consultation through the website of the project: http://www.carim-east.eu/

For more information:

CARIM-East
Robert Schuman Centre for Advanced Studies (EUI)
Convento
Via delle Fontanelle 19
50014 San Domenico di Fiesole
Italy
Tel: +39 055 46 85 817
Fax: + 39 055 46 85 770
Email: carim.east@eui.eu

Robert Schuman Centre for Advanced Studies
http://www.eui.eu/RSCAS/

Table of Contents

Abstract

How does the emigration of ‘top scientific brains’ impact the development of the next generation of scientists? I provide new empirical evidence on the impact of emigration on human capital formation by drawing upon the exodus of Russian scientists after the end of the Soviet Union. I create a novel panel dataset based on scientific publications to estimate emigration of former Soviet scientists combined with official Russian statistics on the production of PhDs aggregated at the regional and scientific field levels. I show that the emigration of scientists in the post-Soviet period is associated with lower production of PhDs measured by admissions, graduates, and the number of students. The results suggest that emigration is not increasing investment in human capital at the PhD level. Possible explanations are that there is a lack of mentors to train the next generation of PhD students and that émigrés are acting as channel for the younger generation to emigrate to pursue PhD studies abroad.

1. Introduction and Motivation

Growth models have pointed to the importance of human capital, particularly in the science and engineering (S&E) fields, as important inputs for innovation and for economic growth (Romer 1990). Thus, for developing countries, the production and retention of high-skilled workers in the S&E sector may be especially important as a development strategy. In recent years, S&E labor forces have been growing in many developing countries, particularly China, yet evidence shows that there continues to be a significant brain drain of scientists, particularly from the developing to the developed world, after they are trained (Weinberg 2011, Freeman 2005). Policymakers have tended to worry about the negative impacts of brain drain, although there is awareness that there may be benefits to the emigration of the highly-skilled (see e.g. Docquier, Rapoport 2012, Gibson, McKenzie 2011; Stark 2004). While there has been a recent increase in studies providing empirical evidence on the impacts of brain drain on sending countries, many open questions remain.

In this paper, I focus on exploring one aspect of the potential impacts of the emigration of the highly-skilled – how the emigration of the 'top scientific brains' impacts the development of the next generation of scientists in the source country. I draw upon an example from recent history to provide empirical evidence on brain drain and high-level human capital formation – the exodus of highly skilled Soviet-trained scientists after the end of the Soviet Union beginning in the early 1990s, primarily to Israel, the US and Western Europe.

As Russia began recovering from the economic collapse of the 1990s, much was written about the size of the scientific brain drain to countries abroad as well to other sectors of the economy. Concern about the loss of these highly-skilled individuals is still very salient in the Russian media and among policymakers, and Russia has embarked on new efforts to try to revitalize the science sector and recover from the loss of scientists abroad. However, due to lack of data on a number of fronts, including reliable numbers concerning the emigration of Russian scientists, very little is still known about the measurable impacts and to what extent there have been benefits in addition to the more visible costs.

The economics of immigration literature has suggested the possibility of a 'brain gain', where emigration of the highly-skilled can lead to an increase in human capital levels. These studies have pointed to e.g. the role of remittances in reducing credit constraints that allow for greater educational investments, the return of emigrants home after gaining further training abroad, or more indirect channels for increasing human capital, such as through the networks with diaspora that increase flows of knowledge and ideas to the sending country (e.g. Agrawal, Kapur, McHale, Oettl (2011) for India; Gökbayrak (2009) for Turkey).

An important part of the 'brain gain' literature has also suggested that when the return to education abroad is higher than at home, emigration can lead to greater incentives in the sending country for individuals to acquire education. In this case, emigration leads to greater investments in education by impacting *expectations* about future emigration possibilities (see e.g. Docquier, Rapoport 2012, 2001; Stark and Wang, 2002). Thus, according to this model, under certain theoretical conditions, there can be cases of "beneficial brain drain", when the incentive effect (additional investment in human capital) outweighs the actual loss in human capital due to emigration (Beine, Docquier, Rapoport 2008). Using cross-sectional data on emigration rates and gross human capital formation from many countries, Beine, Docquier, and Rapoport (2008) provide evidence that skilled migration prospects, measured by the skilled emigration rate, positively impact human capital formation.

The emigration of the highly skilled can also have negative impacts on human capital formation apart from the direct losses from emigration. First, the emigration of the highly-skilled may constrain the supply of teachers and mentors necessary for subsequent generations to gain the requisite human capital. In other words, if the older cohort emigrates, then there is a lack of high-human capital individuals present to facilitate human capital formation in the younger cohorts in the sending country, and there are fewer opportunities for potential knowledge spillovers. For example, using the expulsion of Jewish scientists from Germany during World War II by the Nazis as a natural experiment, Waldinger (2010) shows that the emigration of scientists can impact the quality of training of the next generation. He shows that after the Nazis expelled Jewish scientists during World War II, the subsequent cohort of PhD students had lower productivity as measured by publications in a top journal, citations, and the likelihood of becoming a full-time professor. Waldinger argues that university quality measured by the quality of professors has an important impact on PhD student outcomes.

While not well documented yet, another possibility is that émigrés act as channel for the younger generation to emigrate to pursue studies abroad through their networks, so that the "drain" can happen even earlier for this generation and leads to lower human capital levels in the country. Finally, a related possibility is that in addition to affecting the levels of human capital in the sending country, the emigration of the highly-skilled can impact the *type* of human capital acquired. The loss of top scientists in certain fields may lead to change in fields pursued by the next generation of PhDs, so that then the distribution of potential PhDs may shift over time.[1] If these other fields contribute less to productivity in the economy by creating less knowledge that contributes to economic growth, then emigration may have further negative economic impacts. While empirical evidence on this issue is still sparse, survey evidence collected by Gibson and McKenzie (2010) of high school students in several developing countries show that in addition to leading them to study more, potential migration prospects also changed *what* top high school students studied (see discussion in Gibson, McKenzie 2012).

In this paper, I use the event of the large-scale emigration of scientists that followed the end of the Soviet Union to examine this link between the production and retention of scientists, and in doing so provide new evidence for a question that has been of interest in the economics of immigration literature - how the emigration of high-skilled individuals can impact the level of human capital in the source country. I use data from scientific publications in the Thomson Reuters ISI Web of Science database to estimate emigration by former Soviet scientists and combine them with official Russian statistics on the production of PhDs aggregated at the regional and scientific field levels, and create annual panels for the 1990s. The empirical analysis focuses on providing evidence on the link between emigration rates and the production of PhDs, a measure of high-level human capital. Emigration rates are typically used as a proxy for migration prospects among non-emigrants (Docquier and Rapoport 2012), but as described above, there may be other mechanisms driving the relationship between emigration and human capital formation apart from the channel of expectations about future migration possibilities, which I discuss.

I show that when holding the regions constant, the emigration of scientists in the post-Soviet period is associated with lower production of PhDs as measured by total admissions, total graduates, and overall number of PhD students. This effect seems to mainly be true for regions other than the city of Moscow. A concern with the empirical approach is that emigration may be endogenous, since it may be the case that e.g. an unobserved factor is driving both emigration and PhD production, or that there is reverse causality, so that PhD enrollment is impacting emigration. Thus, I also use an instrumental variables approach where I instrument for emigration in the regions with two instruments, the number of citations to papers published by researchers in a Russian region in a given year by researchers in the United States and the distribution of all emigrants (not only scientists) to non-FSU countries across Russian regions shortly after the end of the USSR.

The results of the empirical analysis suggest that rather than inducing individuals to invest in human capital in the home country, emigration may be reducing the production of PhDs. While further quantitative analysis to identify the mechanisms behind this negative relationship is beyond the scope of this paper, several possible stories are supported by qualitative evidence. Based on interviews conducted with Russian scientists, one possible explanation is the role of the networks that the émigrés

[1] This could result from a number of factors, such as expectations about future career prospects in the sending country, the lack of mentors, or the less vibrant scientific community in certain fields.

created, so that they acted as a channel for the younger generation to emigrate to pursue PhD studies abroad. Another possible explanation is that the exodus of scientists led to a lack of mentors for the next cohort, which limited possibilities for human capital formation the next generation. The emigration of scientists may have also contributed to changes in institutional priorities in Russia to shift enrollment away from PhD programs or to certain new fields to gain further funding. Further research is needed to understand whether emigration indeed contributed to a shift in PhD production abroad or whether these or other reasons explain the negative relationship.

In the next section, I provide some background on emigration after the collapse of the Soviet Union and about the Russian science sector. In Section III, I describe the construction of the dataset and the empirical strategy. The results and discussion follow in sections IV and V.

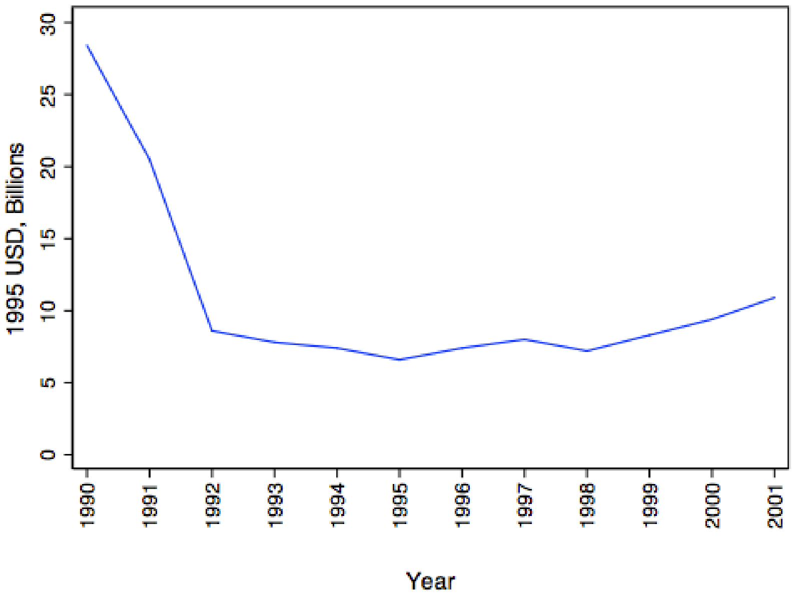
2. Background on the Emigration of Scientists After the USSR

While the USSR had a large scientific community, it was relatively closed to contact with researchers outside of the USSR and the Eastern bloc, and scientists were rarely able to travel outside of the USSR. Graham and Dezhina (2008) describe many of the key features of the Soviet science system, including a separation between teaching and research, political restrictions that included secrecy, discrimination against ethnic groups, and suppression of certain scientific fields for ideological reasons. Scientists worked primarily in the Academy of Sciences, universities, and industrial and military facilities. The focus of this analysis is on scientists publishing in the top scientific journals, and this mainly includes researcher scientists who were in the Academy of Sciences and other institutions conducting basic research.

When the Soviet Union collapsed in 1991, there were dramatic drops in funding for science and the wages of scientists. Figure 1 shows the significant decline in R&D funding after 1991. Based on interviews conducted with scientists in former Soviet Republics about this period, it appears that many scientists did not receive their salaries for some periods after the end of the USSR, or received extremely low salary payments, although this varied by region.[2] Larger cities, particularly Moscow, had more resources.

[2] Interviews conducted with scientists in Estonia, Tajikistan, and Ukraine in 2009, Azerbaijan and Georgia in 2010, and Russia in 2012.

Figure 1. Russian R&D Funding, 1990-2001



Source: NSF Science & Engineering Indicators (2004)

The end of the USSR also brought about many freedoms, particularly greater mobility and contact with the western world, as well as alternative career options in the private sector.[3] Many scientists emigrated abroad to the United States, Israel or Europe throughout the 1990s. Other scientists remained at home and sought opportunities to continue their research, but many also left science completely and pursued other career options. It has been difficult to estimate the number of scientists who emigrated, but Graham and Dezhina (2008) cite conservative estimates of 7,000 researchers leaving Russia from 1993-1996, while they note that less conservative estimates are much higher at 30,000-40,000 researchers emigrating during the same time period. Gokhberg and Nekipelova (2001) use data from the Ministry of Internal Affairs (MVD) and the State Committee on Statistics (Goskomstat) and estimate approximately 20,000 individuals working in the "Science and Scientific Services" sector emigrated during the 1990s, although many of these individuals would not have been research scientists.

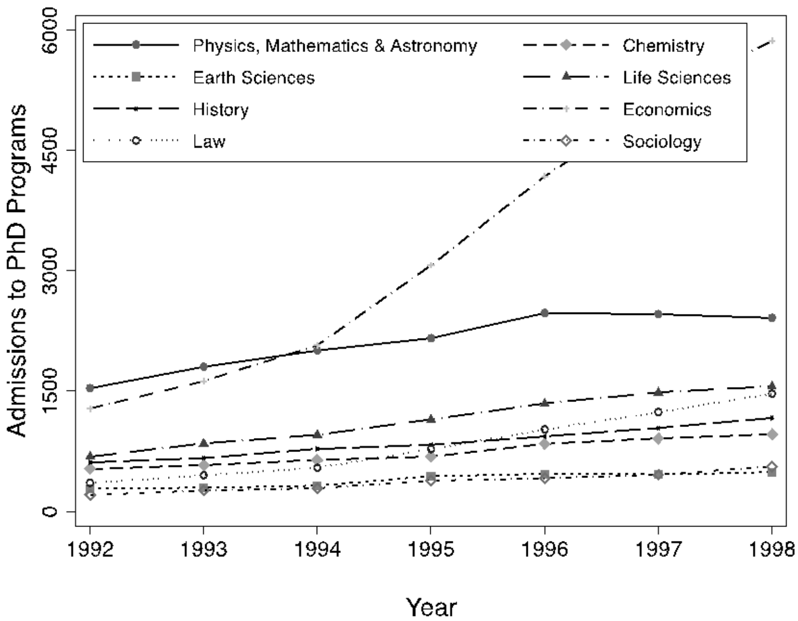
During the 1990s, the Russian government took measures to reform the science sector in response to the changing environment. According to Saltykov (1995), as early as 1992, the Russian government emphasized a policy of "openness to the scientific community and a pragmatic approach to international scientific collaboration" when negotiating with foreign scientific organizations and governments. Moreover, there were many foreign grant programs aimed at fostering exchanges and international collaboration between Russian and Western collaborators. However, challenges made science and international collaboration difficult during the 1990s. Challenges facing scientists included political instability, organizational turnover that made long-term funding agreements difficult to implement, difficulty transferring funds due to the underdeveloped banking system, high taxation and customs duties, lack of effective intellectual property rights, poor infrastructure, lack of a shared language (both linguistic and cultural), and external regulations (OECD, 1994). Thus, emigration was sometimes seen as the only option to continue to do science.

[3] The Law on Employment in 1991 allowed Russian citizens to be employed abroad.

As Russia was losing its Soviet-trained scientists to other countries, new cohorts of students were making decisions to become scientists and enter PhD programs. Survey data of Russian youth shows that throughout the 1990s, while self-reported interest in obtaining higher education decreased, enrollment actually started to increase (see Kovaleva 1999). Moreover, despite the low funding levels and uncertainty about the future of the S&E sector, the number of entrants to PhD programs ("Aspirant") was actually increasing during the 1990s. Figure 2 shows the number of entrants to PhD programs by select fields by year. It shows that throughout the 1990s, the number of individuals entering PhDs in the key scientific fields focused on in this paper (Physics, Mathematics & Astronomy, Chemistry, Earth Sciences, and Life Sciences) was increasing slightly overall. Comparing enrollment in these fields to a selection of other fields shows that there is a sharp increase in PhD enrollment in the field of Economics during this period.

One possibility for the overall increase in PhD enrollment that I investigate in this paper is that given the ability of the older cohort of scientists to emigrate, the younger generation may have viewed PhD studies a way to emigrate later. Other possibilities are that the unstable economic situation led students to pursue PhD studies as a way to protect themselves from the economic uncertainty in the short-run, and allowed them more time to see which sectors would provide the best opportunities. It has also been suggested that PhD enrollment increased as a way for young males to avoid required military service. For my analysis, if the latter reasons are driving the increase in PhD enrollment, then I should not find a significant relationship between PhD enrollment and the emigration rate of scientists. However if another common unobserved factor is leading to the emigration of scientists and PhD enrollment, then my estimates will be biased. I discuss this issue further in Section III and describe an instrumental variables approach to address the potential endogeneity of emigration.

Figure 2. Admissions to Russian PhD programs by Field



Source: Higher Education in Russia (CSRS, 1999, 1996)

Two well-known Russian émigrés who won the 2010 Nobel Prize in Physics are a useful case for illustrating the possible link surrounding brain drain and the formation of human capital among the next generation of researchers. The winners of the 2010 Nobel prize, Andre Geim and Konstantin Novoselov, were trained in the USSR and Russia respectively, but were working outside of Russia in Manchester in the United Kingdom when they received the prize.

Geim got his PhD during Soviet times from the Institute of Solid State Physics in Chernogolovka in 1987. As described in his Nobel lecture (Geim 2011), he then worked as a staff scientist at the Institute of Microelectronics Technology in Chernogolovka, part of the Russian Academy of Sciences (RAS). In 1990, he received a 6-month fellowship from the British Royal Society to visit Nottingham University. He then did post-doc positions for the next 4 years in Nottingham, Copenhagen, Bath and again in Nottingham. In 1994 he got a permanent academic position in the Netherlands at the University of Nijmegen, followed by a full professorship at the University of Manchester in 2000.

Novoselov, meanwhile, began his PhD in Russia already after the end of the USSR. He was doing his PhD at the Institute for Microelectronics Technology in Chernogolovka in 1997 when he had an opportunity to visit the University of Nijmegen and work with Geim. He subsequently moved to University of Nijmegen to complete his PhD in 1999. They worked closely together and Novoselov also moved to Manchester in 2001 when Geim moved there, but finished his PhD from University of Nijmegen in 2004.

While not necessarily a typical case, the Geim-Novoselov story shows how the emigration of the older generation of Soviet scientists influenced the subsequent generation of researchers through the formation of transnational networks. Interviews with scientists in FSU countries suggest that there were likely other cases like this, where the network of Russian émigrés helped the younger generation emigrate to pursue PhD studies abroad.

3. Data & Empirical Approach

3.1. Dataset Construction

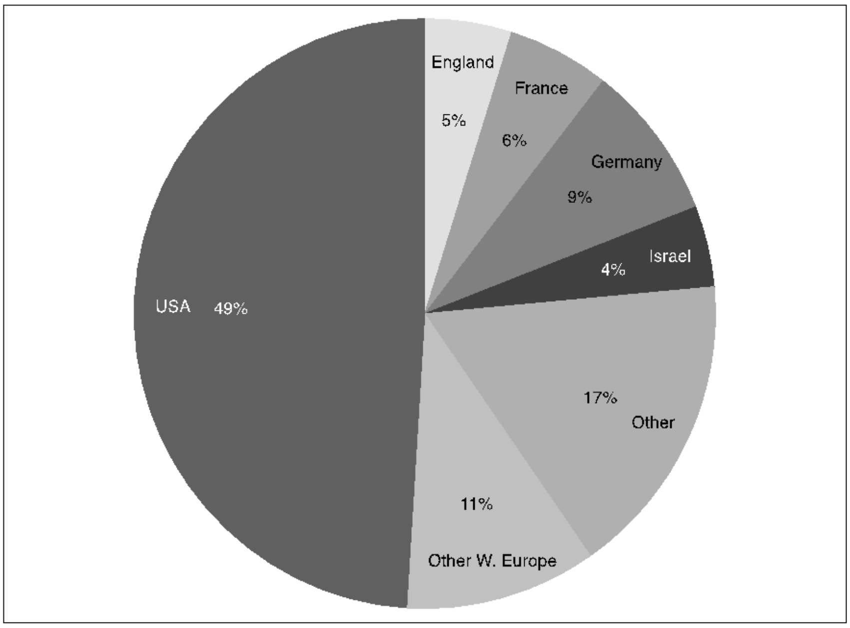
For the analysis, I created measures of emigration based on a novel data source - a panel dataset of Soviet scientists and their publications before and after the end of the Soviet Union. I first identified a sample of scientists who were “doing science” in Russia around the time of the Soviet collapse. I use publication data from the Thomson Reuters Web of Science[4] database to create a sample of Russian scientists who were actively doing scientific research before and after the end of the Soviet Union in 1991.

To do this, I identified the top Soviet and Russian language journals in the ISI and extracted names of all authors publishing in these journals between 1986-1994. The ISI database includes over 100 top journals of the former USSR and Russian language journals. The ISI included many of the top Soviet journals by the 1970s (and subsequently Russian journals). Ganguli (2011) provides a full description of the preparation of the publication data, including information on transliteration and name matching and assigning scientific fields.

Next, I identified the subset of authors who had at least 2 articles between 1980-1990 with an address that included a city in the former Russian Republic of the USSR. I dropped any individuals with a foreign address before 1990. I further restricted to authors who “stayed in science” and I could identify their location, meaning they published at least one article after the end of the USSR through 2005. I then matched each scientist to his or her publications and affiliations, which results in a scientist-year level dataset.

[4] Web of Science ® prepared by THOMSON REUTERS ®, Inc. (Thomson ®), Philadelphia, Pennsylvania, USA: © Copyright THOMSON REUTERS ® 2010. All rights reserved.

Figure 3. Destination Countries of Emigrants



Notes: See Section 3 for a description of the data.

Source: Author's calculations using data from the Web of Science.

Using the affiliation information, I code the location of each scientist in the sample by year. This allows me to assign a country (and a city) to each scientist for each year and identify which individuals emigrated from Russia.[5] I also code the region of each Russian city to be able to match the data to the higher education data described below. Note that I do not account for return-migrants - once I observe that an individual was outside of Russia, they are thereafter coded as an emigrant.[6] Using this individual-level panel data on emigration, I then aggregate to the region and scientific field levels and calculate total emigrants by year and region or field. Figure 3 shows the top destination countries of the emigrants in the sample (the last country I observe them in). Almost half the emigrants went to the United States, and then the top destinations are Germany and other countries in Western Europe.

I finally combine the emigration data aggregated at the region level with official data from Russian statistical yearbooks and data on higher education from publications of the Centre for Science Research and Statistics (CSRS). To create a panel dataset of the key variables for Russian economic regions and scientific fields for years 1992-1999, I draw upon a number of publications, including *Higher Education in Russia / Высшее образование в России* (CSRS 1996, 1999), *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели* (Rosstat, 2002) and *The Russian Statistical Yearbook / Российский статистический ежегодник* (Rosstat, 2010).

---

[5] For years in which I do not observe a scientists' affiliation information, I impute the country based on previous year. If a scientist has multiple affiliations, they are coded as an emigrant as long as one affiliation is foreign.

[6] During the time period studied, 1992-1999, temporary migration was common, and my emigration measure includes these individuals. This lessens the direct loss of human capital and does not account for the possibility of an increase in mentors who return, but the mechanism regarding the prospect of migration and the role of transnational networks might still affect the decisions of the younger cohort even if scientists returned later.

3.2. Empirical Model

For the empirical analysis, I estimate how emigration impacts high-level human capital formation measured by the production of PhDs. Using panel data for Russian regions, I run the following regressions for region i in year t:

$$\mathbf{H_{it} = \alpha + \beta E_{it} + \theta X_{it} + \gamma_i + \delta_t + \varepsilon_{it}} \ (1)$$

where H is a measure of human capital at the PhD level, E is a measure of emigration, γ_i is a region fixed effect, and δ_t are year fixed effects. The measures used for H, the measure of human capital at the PhD level, include the following:

1. *Number of PhD students (Численность аспирантов по отраслям наук)*
2. *Admissions to PhD programs (Прием в аспирантуру)*
3. *Graduates from PhD programs (Выпуск из аспирантуры)*

The measure of emigration, E, could be calculated in various ways. The preferred measure for this analysis is the total number of scientists from region i who publish with a foreign affiliation for the first time in year t. Thus, it is a measure of the outflows of scientists by year (rather than the stock of emigrants). Since the analysis uses panel data and includes region fixed effects, the results are identified off of year-to-year changes in the number of emigrants, so the overall size of the scientific market by region is accounted for, and it is not necessary to adjust for the population of the region. I also calculate the emigration rate, measured as the total number of scientists I observe publishing with a foreign affiliation divided by the total number of scientists in the region in that year (including the emigrants). Previous studies measure "migration prospects" using the emigration rate (Docquier and Rapoport 2012).

There are some timing issues to consider in the specification used in the analysis. First, given that the date of the first publication abroad is a very noisy measure of the year of migration, a more accurate assessment of the migration year would be preferred using information from CVs or other data not culled from publications. Unfortunately, the lack of CVs and other information for the scientists in my sample (via websites, etc.) makes it difficult to determine a more exact move year. Second, there may be a lag between the emigration of scientists and when this emigration is salient for the younger generation in making decisions about investing in human capital at the PhD level at home. In the analysis, I assume that the time between actually emigrating and publishing abroad corresponds to an appropriate lag time for students to be aware of their emigration and make decisions about PhD training.

I also include the following time-varying variables in the specification as controls, X_{it}, to account for other factors that may impact human capital formation across regions and over time:

- *Economically active population:* The total labor force in the region, including the employed and the unemployed (in thousands of individuals).
- *Regional Budget:* The budget of the regions of the Russian Federation, including the budget for education, in billions of rubles (until 1998, then millions of rubles).
- *R&D organizations:* The number of organizations in the region carrying out research and development, including government, private, education and non-profit organizations.

Table 1. Summary Statistics: Russian Economic Regions, 1992 & 1999

Economic Region	Emigration Rate	PhD Admissions	Econ. Active Pop.	Budget	R&D Orgs
1992					
Central	0.0163	959	11226	258.1	611
East Siberian	0.0000	918	4695	163.9	204
Far Eastern	0.0000	335	4353	230.8	230
Moscow	0.0184	5941	4693	191.8	841
North Caucasus	0.0041	705	7174	171.3	368
St. Petersburg	0.0139	2009	2644	64.8	401
Urals	0.0093	860	10364	400.2	439
Volga	0.0244	951	8541	290.6	422
Volga-Vyatka	0.0135	388	4325	117.6	200
West Siberian	0.0127	918	7684	1112.4	471
1999					
Central	0.0153	2931	10509	59649.6	574
East Siberian	0.0000	1677	4378	40971.4	144
Far Eastern	0.0000	1193	3768	49801.4	154
Moscow	0.0117	11823	4278	87690.5	899
North Caucasus	0.0087	2644	7656	37830.3	249
St. Petersburg	0.0114	4359	2426	26066.4	483
Urals	0.0032	2771	9976	78033.1	375
Volga	0.0000	3139	8260	65069.5	376
Volga-Vyatka	0.0073	1386	4189	21817.0	156
West Siberian	0.0115	3425	8595	169238.5	381

Notes: Economically active population is measured in thousands of individuals; Budget is measured in billions of rubles (until 1998, then millions of rubles).

Sources: Author's calculations using data from the Web of Science*; Higher Education in Russia / Высшее образование в России* (CSRS 1996, 1999), *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели* (Rosstat, 2002) and *The Russian Statistical Yearbook / Российский статистический ежегодник* (Rosstat, 2010).

Table 1 shows summary statistics for the key variables by Russian regions for the first and last years in the region-level panel, 1992 and 1999. Note that Russia has 12 economic regions, but 4 are not included because there were no scientists appearing in the publications data from those regions (Northwestern, Central Black Earth, Northern, and Kaliningrad). I also include Moscow and St. Petersburg, the two largest Russian cities, as separate regions even though they are part of the Central and Northwestern regions, respectively.

Table 1 shows that the emigration rates are rather low, but there is variation across regions and time (even though only 2 years are shown here). The other variables also show that there is significant variation across regions. Moscow is clearly more prominent in terms of scientific indicators, with a much larger number of PhD admissions and R&D organizations.

There are a few data limitations that may impact the econometric estimation of (1). First, the panel data is at the region-year level for years 1992-1999, however the control variables above were not available to me for 1993 and 1994, so these years are omitted in the analysis. Ideally, I would like to run (1) on region-field-year level data, but data at this narrower level is not available to date. Instead, measures of P, human capital formation at the PhD level, are aggregate measures at the region level that include PhD students in all fields (including e.g. social sciences and humanities). However, the measure of emigrants, E, only includes scientists in the ‘hard science’ fields of Physics, Mathematics & Astronomy, Chemistry, Earth Sciences, and Life Sciences, which is the focus of this analysis.

As Figure 2 showed, most fields were stable or growing slightly overall during the 1990s, but there was a sharp increase in Economics PhDs during this time. Including PhD students in all fields poses a mismeasurement issue for the left-hand side variable. However, this does not lead to bias in the estimated coefficients, unlike mismeasurement in a right-hand side variable (Hausman 2001). Rather, mismeasurement in the left-hand side variable leads to lower precision in the estimated coefficients, so the inclusion of PhD students in all fields would lead to more noise and lower t-statistics, so that it would be less likely that I would find a significant effect of the emigration of scientists.

However, if some unobserved factor is impacting PhD student enrollment in these other fields as well as the emigration of scientists, then I might be mistakenly be attributing the effect to emigration. For example, it may be that economic factors that ‘pushed’ the scientists abroad in the 1990s also induced the younger generation to enter PhD studies in e.g. Economics as a more stable short-run opportunity. This would then attribute the changes in PhD production to emigration, when in fact it is due to economic conditions.

This raises an important econometric issue in estimating (1) concerning the potential endogeneity of migration. In addition to the possibility is that some other unobserved factor is driving both the production of PhDs and emigration, there is also concern about reverse causation. For example, it may be that emigrants are more likely to leave from certain regions or years when PhD enrollment is low, resulting in a correlation with the error term. Then, the enrollment of PhD students may be affecting the emigration of scientists, and not the other way around.

While the econometric specification in (1) relies on panel data and includes region and year fixed will account for unobserved factors by region and year and alleviate some of the endogeneity concerns, there still may be unobserved factors that change over time that influence human capital at the PhD level, so there is some part of the error term in (1) that is correlated with H.

In order to account for these concerns about the exogeneity of emigration, I try an instrumental variables approach where I instrument for emigration. The first instrument is the number of citations to papers published by researchers in a Russian region in a given year by researchers in the United States. The reasoning is that the demand for researchers abroad is higher if their research is well known. In this case, citations reflect the renown of the Russian scientists’ research, and if researchers abroad were familiar with their research, it is more likely that Russian scientists had opportunities to emigrate.

However, citations to papers published in the region should not be correlated with decisions of students to enter PhD programs.

The second instrument follows the approach used recently in the economics of immigration literature that relies on the historical distribution of immigrants across US destination cities as an instrument for the recent distribution of immigrants (see e.g. Hunt and Gauthier-Loiselle, 2010; Cortes, 2008). The basic idea of the instrument is that potential immigrants consider immigrant networks when making their location choices, but the historical distribution of immigrants is not likely to be correlated with more recent outcomes of interest. In this case, rather than the historical distribution of immigrants arriving in cities in the destination country, I use the distribution of *emigrants* across Russian regions shortly after the end of the USSR. Given that emigration did not really occur before the end of the USSR, it is not possible to use data on the historical distribution of emigrants as other studies have (i.e. 10 or more years before the years of interest). However, using a similar logic based on the importance of immigrant networks, emigration will be more likely from regions with greater initial emigration, but should not be correlated with subsequent PhD enrollment. The earliest available data by region I could access comes from the 1993 Demographic Yearbook of Russia / *Демографический ежегодник России* (Goskomstat, 1993). The instrument is calculated in the following way:

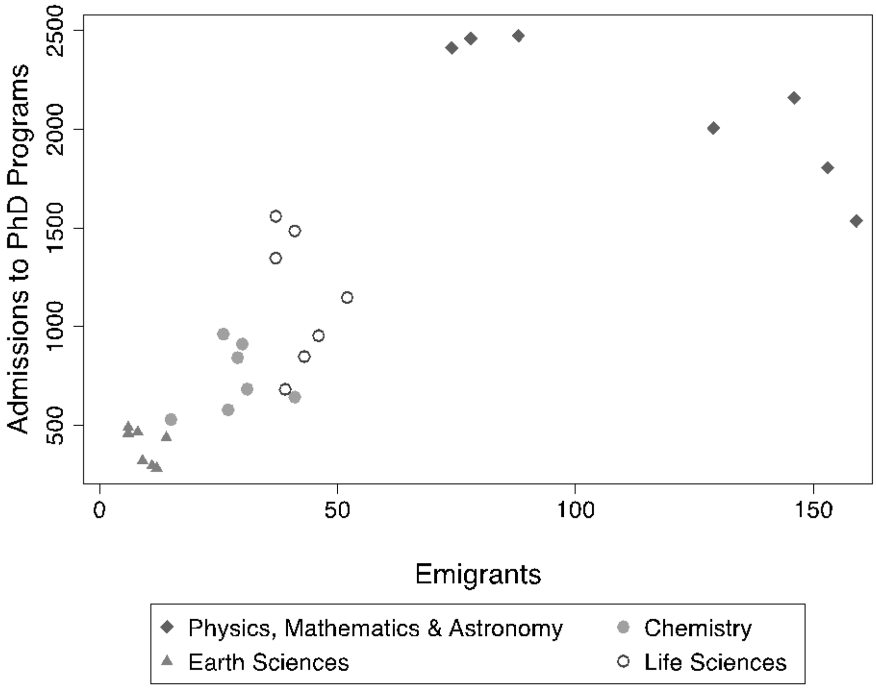
$$\frac{AllEmigrants_{i1993}}{AllEmigrants_{1993}} \times ScientistEmigrants_t$$

where $AllEmigrants_{i1993}/AllEmigrants_{1993}$ is the share of all emigrants from Russia to non-FSU countries from region i in 1993 and $ScientistEmigrants_t$ is all scientists who emigrated in year t. This instrument essentially uses the 1993 distribution of all emigrants across Russian regions to weight the number of scientist emigrants in subsequent years. The first stage estimates show that both instruments are positively correlated with emigration, and the instruments appear to be strong in the first stage, with an F-statistic of 115.

4. Results

Before presenting the regression results, I show a plot of the main variables of interest using data from the panel at the scientific field-level. Figure 4 shows admissions to PhD programs and total emigrants, with each point in the plot representing an observation at the scientific field-year level for 1992-1998. If we were to just look at the data points without knowing the field, then he relationship between the variables would appear to be positive, suggesting that perhaps the incentive effect is at play, and that emigration might be leading to greater investment in human capital at the PhD level due to the increased migration prospects. However, looking at the variation within fields, it is clear that we must exploit the year-to-year variation within a field or region to account for the overall levels of PhD enrollment and emigration. Thus, I now turn to the econometric results using the region and field panel data, which allow us me to hold the region / field constant.

Figure 4. PhDs Admissions and Total Emigrants, Field-Year



Notes: See Section 3 for a description of the data.

Sources: Author's calculations using data from the Web of Science; *Higher Education in Russia / Высшее образование в России* (CSRS 1996, 1999), *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели* (Rosstat, 2002) and *The Russian Statistical Yearbook / Российский статистический ежегодник* (Rosstat, 2010).

Table 2 shows the main regression results corresponding to specification (1). It shows the results for each of the 3 main dependent variables. Columns 1, 3, and 5 show the results when not controlling for the additional time-varying variables. The results show that there is a negative relationship between total emigrants publishing abroad in a given year and the total number of PhD students as well as the total number of new PhD admissions. The number of emigrants is not significantly related to the number of PhD students who are graduating in this specification, although it is significant in the IV results presented later.

Table 2. Regression Results: Emigration and PhD Production, Region Panel

	(1) PhD Students	(2) PhD Students	(3) PhD Admissions	(4) PhD Admissions	(5) PhD Graduates	(6) PhD Graduates
Total Emigrants	-72.01**	-68.93**	-38.93**	-30.37**	-24.32	-17.58
	(12.947)	(13.858)	(13.283)	(8.704)	(16.267)	(13.638)
Econ. Active Pop.		-0.12		-0.10		0.03
		(0.404)		(0.231)		(0.288)
Budget		0.01*		0.01*		0.00
		(0.006)		(0.004)		(0.005)
R&D Orgs		0.38		7.35**		6.58*
		(4.645)		(2.586)		(2.862)
Constant	4750.30**	5684.56	1539.74**	-1832.53	1345.87**	-2933.69
	(285.055)	(5540.073)	(224.147)	(2247.052)	(228.110)	(3206.746)
Region FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
R2	0.995	0.996	0.986	0.991	0.974	0.977
Nb. of Obs.	60	60	60	60	60	60

Notes: OLS estimation. See Section 3 for description of data. Robust standard errors in parentheses. $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Sources: Author's calculations using data from the Web of Science*; Higher Education in Russia / Высшее образование в России* (CSRS 1996, 1999), *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели* (Rosstat, 2002) and *The Russian Statistical Yearbook / Российский статистический ежегодник* (Rosstat, 2010).

When including the 3 control variables, the coefficient on the number of emigrants is smaller, but still significant for the number of PhD students and PhD admissions. The effect implies that for each additional emigrant in a given year, there is a decrease of close to 70 PhD students and 30 new PhD students. This is approximately a 1.4 percent decrease in the number of PhD students on average and a 2 percent decrease in PhD admissions. The coefficient on the budget control variable is positive and significant, suggesting that increases in the budget are related to increases in PhD admissions and graduates. While the budget variable includes other expenses in the region beyond education, the significance of the variable indicates that year-to-year changes in the budget are correlated with PhD admissions and graduates, regardless of whether it is due to the direct expenditure on education or due to other unobserved factors correlated with PhD admissions and graduates. The number of R&D organizations is also positively related to both admissions and graduates, suggesting that the presence of new organizations leads to greater human capital formation at the PhD level.

As noted earlier, in these specifications, the dependent variables also include PhD students not enrolled in the scientific fields of the emigrant-scientists, which might be leading to less precision in the estimated coefficients. As a robustness check, I also run a similar specification on field-level panel data in Table 3 that limited the analysis to the key scientific fields of interest (Physics, Mathematics & Astronomy, Chemistry, Earth Sciences, and Life Sciences). I do not have additional field-level controls, but the coefficient on emigration, while smaller, is also negative and significant for PhD students and PhD admissions, but insignificant for graduates, so the OLS results across the specifications are similar.

Table 3. Regression Results: Emigration and PhD Production, Field Panel

	(1) PhD Students	(2) PhD Admissions	(3) PhD Graduates
Total Emigrants	-11.70**	-3.97**	-0.89
	(2.235)	(1.347)	(1.338)
Constant	2055.98**	534.46**	588.83**
	(212.180)	(104.027)	(53.114)
Field FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R2	0.986	0.981	0.982
Nb. of Obs.	28	28	28

Notes: OLS estimation. See Section 3 for description of data. Robust standard errors in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$

Sources: Author's calculations using data from the Web of Science*; Higher Education in Russia / Высшее образование в России* (CSRS 1996, 1999), *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели* (Rosstat, 2002) and *The Russian Statistical Yearbook / Российский статистический ежегодник* (Rosstat, 2010).

Given that the city of Moscow is very different from other parts of Russia, as was seen in Table 1, I next include an interaction term, interacting a Moscow dummy with the number of emigrants. The interaction term is not significant in any of the 3 models that include the control variables. Yet for PhD students and PhD admissions, while noisy, the results suggest that the non-Moscow regions mainly drive the negative effect of emigration on PhD enrollment. In specifications where I use the full panel and do not include the controls (which allows me to include years 1993 and 1994), the interaction term is then significant for both PhD students and PhD admissions, suggesting that the effect of emigration for Moscow is close to zero while it is negative for the other regions.

Table 4. Emigration and PhD Production, Moscow Interactions

	(1) PhD Students	(2) PhD Admissions	(3) PhD Graduates
Total Emigrants	-37.17*	-17.35	-13.66
	(18.241)	(10.702)	(10.409)
Total Emigrants X Moscow	-33.31	-13.65	-4.11
	(22.555)	(14.747)	(17.323)
Econ. Active Pop.	0.02	-0.05	0.04
	(0.377)	(0.251)	(0.292)
Budget	0.01*	0.01*	0.00
	(0.005)	(0.004)	(0.005)
R&D Orgs	0.22	7.29**	6.56*
	(4.786)	(2.643)	(2.905)
Constant	4001.53	-2522.13	-3141.38
	(5446.784)	(2489.142)	(3197.236)
Region FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R2	0.996	0.991	0.978
Nb. of Obs.	60	60	60

Notes: OLS estimation. See Section 3 for description of data. Robust standard errors in parentheses. + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Sources: Author's calculations using data from the Web of Science*; Higher Education in Russia / Высшее образование в России* (CSRS 1996, 1999), *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели* (Rosstat, 2002) and *The Russian Statistical Yearbook / Российский статистический ежегодник* (Rosstat, 2010).

Finally, the regression results instrumenting for emigration are shown in Table 5. The first instrument is the lagged number of citations to papers published by researchers in a Russian region in a given year by researchers in the United States as an instrument for migration.[7] The second instrument is the distribution of *emigrants* across Russian regions to non-FSU countries in 1993. The results show that the coefficient on emigrants is negative and significant for all measures of PhD production (Total, Admissions, and Graduates). The coefficient for total PhD students is smaller, suggesting that the OLS estimates were overstating the negative relationship between emigration and the number of PhD students. The IV estimates also show a significant negative impact on PhD graduates, while the OLS estimates were not significant. If these are valid instruments, these estimates should alleviate concerns that the negative relationship between total emigrants and the measures of PhD production from the OLS estimates are driven by an unobserved factor or are the result of reverse causality.

Table 5. IV Regression Results: Emigration and PhD Production

	(1) PhD Students	(2) PhD Admissions	(3) PhD Graduates
Total Emigrants	-53.57**	-42.38**	-47.25**
	(7.295)	(5.602)	(3.649)
Econ. Active Pop.	-0.09	-0.13	-0.03
	(0.418)	(0.211)	(0.243)
Budget	0.02*	0.01*	0.00
	(0.007)	(0.004)	(0.005)
R&D Orgs	2.66	5.57*	2.18
	(3.322)	(2.840)	(1.972)
Constant	3810.59	-367.14	685.62
	(5010.590)	(1833.197)	(2673.649)
Region FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
R2	0.995	0.990	0.968
Nb. of Obs.	60	60	60

Notes: OLS estimation. See Section 3 for description of data and instruments. Robust standard errors in parentheses.

$^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$.

Sources: Author’s calculations using data from the Web of Science*; Higher Education in Russia / Высшее образование в России* (CSRS 1996, 1999), *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели* (Rosstat, 2002) and *The Russian Statistical Yearbook / Российский статистический ежегодник* (Rosstat, 2010).

5. Discussion

In this paper, I use the large-scale emigration that followed the end of the Soviet Union to examine the connection between the production and retention of scientists. I use new data on the emigration of scientists from Russia during the 1990s and combine it with regional and field-level annual panel data on the production of PhD students to estimate whether emigration impacts human capital formation among subsequent generations. The results indicate that emigration of scientists is associated with lower production of PhDs as measured by admissions to PhD programs and the overall number of PhD students.

---

[7] I use the lagged value of citations, since the citations would precede the actual migration of the scientists. I also tried a double lag of the citations, and in this case, the coefficient on migration is also negative, but is larger.

The findings suggest that rather than inducing individuals in the sending country to invest in human capital as a result of increased migration prospects, emigration is reducing the production of PhDs. While further quantitative analysis to identify the mechanisms behind this negative relationship is beyond the scope of this paper, there are several possible explanations that are also supported by suggestive qualitative evidence which would be fruitful areas of future research. One possible explanation is that émigrés may have been acting as channel for the younger generation to emigrate to pursue PhD studies abroad. Further research that empirically examines whether emigration may be contributing to a shift in PhD production from developing countries to developed countries through such émigré networks would shed light on this phenomenon.

One result from the analysis is that the non-Moscow regions seem to be mainly driving the negative effect of emigration on measures of PhD production. Given that Moscow is so different from other regions in Russia in terms of e.g. higher wages, a larger scientific community, and greater educational and career options, this suggests that there are likely to be certain characteristics of regions contributing to the negative relationship, and further analysis with a richer datasets could help parse out which factors are more important. More generally, such analysis could be expanded to see whether different characteristics across sending countries are associated with greater or less human capital formation.

Finally, further research on other outcomes of interest besides the measures of PhD production analyzed here would also be a useful, such as studying whether emigration impacted the type of human capital acquired by the next generation. The loss of top scientists in certain ‘hard science’ fields may have led to change in fields or programs pursued by the next generation of students. If the allocation of individuals to these fields or programs leads to less knowledge produced that contributes to productivity and economic growth, then emigration may have further negative economic impacts.

The analysis in this paper and the other lines of potential research discussed would contribute to several literatures concerned with the impacts of brain drain. First, this paper provides additional empirical evidence related to the possible beneficial impacts of brain drain, which has gained increased visibility in the brain drain literature and has argued that the prospect of migration to countries where the return to education is higher can lead to greater investments in education at home. This paper also points to further research areas for the economics of science and education literature that is concerned with how the presence of scientists and high-quality faculty impacts PhD student outcomes. Finally, these results contribute to the development literature and will be of interest to policymakers considering how emigration may impact the development of human capital, particularly in the science and engineering (S&E) fields, sectors critical for innovation and long-run economic growth.

References

Agrawal A., Kapur D., McHale J., Oettl A. (2011). Brain Drain or Brain Bank? The Impact of Skilled Emigration on Poor-Country Innovation. *Journal of Urban Economics*, 69(1): 43-55.

Beine M., Docquier F., Rapoport H. (2008). Brain Drain And Human Capital Formation In Developing Countries: Winners And Losers. *The Economic Journal*, 118(528): 631-652.

Beine M., Docquier F., Rapoport H. (2001). Brain Drain and Economic Growth: Theory and Evidence. *Journal of Development Economics*, 64(1): 275-289.

Cortes P. (2008). The Effect of Low-skilled Immigration on US Prices: Evidence from CPI data. *Journal of Political Economy*, 116(3): 381-422.

CSRS (1999, 1996). Higher Education in Russia / Высшее образование в России. Moscow: Centre for Science Research and Statistics.

Docquier F., Rapoport H. (2012). Globalization, Brain Drain, and Development. *Journal of Economic Literature, 50*(3): 681-730.

Freeman R. B. (2005). Does Globalization Of The Scientific/Engineering Workforce Threaten US Economic Leadership*?. NBER Working Paper No. 11457.*

Ganguli I. (2011). Location and Scientific Productivity: Evidence from the Soviet “Brain Drain”. *Unpublished Manuscript.*

Gibson J., McKenzie D. (2011). Eight Questions about Brain Drain. *The Journal of Economic Perspectives,* 25(3): 107-128.

Geim A. K. (2011). Geim, Andre K. Nobel lecture: Random walk to Graphene. *Reviews of Modern Physics* 83.3: (2011): 851.

Gökbayrak Ş. (2009). Skilled Labour Migration and Positive Externality: The Case of Turkish Engineers Working Abroad. *International Migration,* Vol. 50 (S1): e132–e150.

Gokhberg L., Nekipelova E. (2002). International Migration of Scientists and Engineers in Russia, in: OECD, *International Mobility of the Highly Skilled,* pp. 177-187. Paris: OECD.

Goskomstat (1993). *Demographic Yearbook of Russia / Демографический ежегодник России.* Moscow: Goskomstat.

Graham L., Dezhina I. (2008). *Science in the New Russia: Crisis, Aid, Reform*. Bloomington and Indianapolis: Indiana University Press.

Hausman J. (2001). Mismeasured Variables in Econometric Analysis: Problems from the Right and Problems from the Left. *Journal of Economic Perspectives,* Vol. 15, No. 4: 57-67.

Hunt J., Gauthier-Loiselle, M. (2010). How Much Does Immigration Boost Innovation? *American Economic Journal: Macroeconomics* 2(2): 31-56(26).

Kovaleva N. (1999). Higher Education and the Labour Market in Russia: Trends in the Transition Period, in: D. A. Dyker. S. Radosevic (eds.), *Innovation and Structural Change in Post-Socialist Countries: A Quantitative Approach.* pp. 429-445. New York: Springer.

Romer P. M. (1990). Endogenous Technological Change. *Journal of Political Economy*, 98 (5 pt 2): S71-S102.

Rosstat (2010). *The Russian Statistical Yearbook / Российский статистический ежегодник.* Moscow: Rosstat.

Rosstat (2002). *Regions of Russia: Social and Economic Indicators/ Регионы России. Социально-экономические показатели.* Moscow: Rosstat.

Saltykov B. (1995). New Russian Problems of International Scientific Collaboration, in: V. Koptyug, J. Klerkx (eds), *Science Policy: New Mechanisms for Scientific Collaboration Between East and West*, pp. 3-8. Dordrecht: Kluwer Academic Publishers.

Stark, O. (2004). Rethinking the brain drain. *World Development*, 32(1): 15-22.

Stark, O., Wang Y. (2002). Inducing human capital formation: migration as a substitute for subsidies. *Journal of Public Economics,* 86(1): 29-46.

Waldinger F. (2010). Quality matters: The expulsion of professors and the consequences for PhD student outcomes in Nazi Germany. *Journal of Political Economy,* 118(4): 787-831.

Weinberg B. A. (2011). Developing Science: Scientific Performance and Brain Drains In The Developing World. *Journal of Development Economics,* 95(1): 95-104.