

International scientific collaboration of post-Soviet countries: a bibliometric analysis

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Abstract

One of the major characteristics of research is the role and scope of international collaboration. Patterns of such collaboration are often complex and determined not only by pure academic rationale, but also by political, economic, geographic and cultural factors. The post-Soviet region has several features, which make it a unique unit for analysis of scientific collaboration. Based on bibliometric data for the period 1993-2018 with a 5-year lag, we analyze how international collaboration patterns of post-Soviet countries changed after the collapse of the Soviet Union. Our results show that in the observed period post-Soviet countries significantly changed their patterns of international collaboration, and these changes are country-specific. The analyzed countries moved away from each other, choosing their own international collaboration strategy. We observe a dramatic decrease in scientific collaboration between post-Soviet countries and a significant growth of collaboration with Western countries. With that, the role of post-Soviet countries in international collaboration declined rapidly for many countries.

Keywords: International collaboration, bibliometric analysis, collaboration patterns, fractional counting, post-Soviet countries

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JEL Classification: F55, I23, O19, O57, P52

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1. Introduction

The structure of academic research in a particular country is directly linked with the social, economic and political institutions in the country (Marginson & Rhoades 2002; Graham 1993). The organization of science in the Soviet Union was significantly different from Western Europe and America (Graham 1993). Science in the USSR was characterized by a number of peculiarities that were reflected in the collaboration of Soviet scientists both within the country and abroad. First, despite the fact that in different periods researchers in the USSR had different opportunities to interact with researchers from other countries, throughout this period, internationalization was under government control (Schott 1992). The contacts of Soviet scientists with their Western colleagues were either encouraged or limited but always remained under state control. To travel abroad, including for participation in conferences, internships, etc., it was necessary to obtain a permit. For a significant period, Soviet science was relatively isolated from the West (Krementsov 1996; Kuraev 2014). Individual scientists were persecuted even for publishing in foreign journals (see, e.g., Hollings 2016). Second, the academic system of the USSR was characterized by a high degree of administrative and geographic centralization. Fundamental research was localized mainly in research institutes that were part of the Academy of Sciences. Each republic had its own Academy of Sciences, which was part of the general union system. The headquarters of the Academy of Sciences and most research institutes were located in Soviet Russia (RSFSR). Most of the major research projects and scientific infrastructure were also concentrated in the cities of the RSFSR (Rabkin & Mirskaya 1993). Thus, RSFSR occupied a dominant position in comparison with the other republics (Nesvetailov 1995). At the end of the Soviet period, more than 2/3 of the scientists of the USSR worked in the RSFSR (Mindeli 1991; Rabkin & Mirskaya 1993), and only 6 of the 100 most cited scientists of the USSR worked outside the RSFSR (Garfield 1990). After the collapse of the USSR, Russia should remain the most frequent and powerful collaborator within the region.

After the collapse of the USSR, the general political and institutional framework ceased to exist. Each former Soviet republic began to create and develop its own academic systems. However, not much is known about how international collaboration works in post-Soviet countries. There are several studies which consider international collaboration in post-Soviet countries. Kozak, Bornmann & Leydesdorff (2015) analyzed international collaboration by researchers from the Eastern European countries of the former Warsaw Pact after the breakdown of communist regimes. They concluded that Eastern European countries increased collaboration with Western countries more than among themselves. Chankseliani, Lovakov & Pisyakov (2021) found that all post-Soviet countries have a large proportion of internationally co-authored publications, but they did not analyze the structure of this collaboration.

This study aims to fill this gap and provide an overall picture of international collaboration in the post-Soviet region. The case of post-Soviet countries is especially interesting in terms of analyzing the development of international collaboration. On the one hand, all countries were under the influence of a common science management system, and after the collapse of the USSR, its residual influence could strongly manifest itself in the form of the path-dependency effect. Previous research has shown the influence of path dependencies on the development of research and technology in transitional economies (Karaulova et al. 2016; Klochikhin 2012; Radosevic & Yoruk 2014). On the other hand, in the creation of the new academic systems, various forces acted, exerting a

multidirectional influence, including on the organization of interaction between post-Soviet researchers inside and outside the region. Almost all post-Soviet countries faced deep economic, political and social crises, against the background of which science remained deeply underfunded for a long time (Yegorov 2009). This led to another wave of emigration of the best scientists to the US and Europe (Ganguli 2014). At the same time, many researchers emigrating from the USSR and post-Soviet countries continued to maintain contacts with colleagues and organizations in post-Soviet countries. The remaining researchers were forced to seek additional resources (intellectual and economic) from colleagues from Western countries. The Baltic states actively began the process of integration with the EU, which culminated in the inclusion of these countries into the EU in 2004. This gave these countries access to research funds and academic mobility programs (Allik 2003). However, different players, and especially the EU, have actively promoted research collaboration with former Soviet republics and strengthened economic and cultural ties with them (Ball & Gerber 2005). Thus, it can be expected that post-Soviet countries should have a high level of international interaction, manifested in a high proportion of articles co-authored with researchers from the US and the EU.

Collaboration between the countries that were part of the USSR was also influenced by the transformation processes that took place in the region after the collapse of the USSR. As mentioned above, the RSFSR dominated among the republics of the USSR, and after its collapse, Russia became the legal heir of the Soviet Union, inheriting a significant part of the Soviet scientific infrastructure (Schneider 2013). Continuing the use of this infrastructure by researchers from other post-Soviet countries required collaboration with Russian colleagues. At the same time, some infrastructure facilities remained in the territories of other former republics (for example, The Baikonur Cosmodrome), therefore, their use by Russian researchers also began to require collaboration with researchers from these post-Soviet countries. Consequently, one can expect an intensive collaboration of Russian researchers with researchers from other post-Soviet countries, at least in the first years after the collapse of the USSR. In the 2000's the negative trend for research funding was overturned for some nations including Russia, which significantly expanded its research infrastructure and publication output (Moed, Markusova & Akoev 2018), while in geopolitical terms many ex-USSR countries had their ties with Russia greatly reduced. Another factor in the intensive collaboration of researchers from post-Soviet countries with each other is the commonality of the Russian language, which was actively spreading in all Soviet republics. It was the Russian language that was the main language of scientific communication in the USSR, therefore, after its collapse, the majority of the actively working researchers in the post-Soviet countries knew it.

However, there are factors that could reduce the intensity of collaboration between researchers from Russia and other post-Soviet countries. First, against the background of the economic and political crisis that all former Soviet republics experienced to a greater or lesser extent, scientific research was insufficiently funded for a long time (Yegorov 2009). There was little motivation for researchers from post-Soviet countries to seek additional intellectual and economic resources inside the region. Second, starting from the early years of the post-Soviet period, political tensions and conflicts arose between the Russian authorities and the authorities of some post-Soviet countries. The relationship between Russia and a number of post-Soviet countries became negative both at the institutional level and at the level of personal communication.

The common past and diverging present make the task of measuring and interpreting international collaboration for former USSR countries very interesting. The features of the organization of science in the Soviet period and the transformation processes in the post-Soviet period raise a number of questions about how international scientific collaboration is organized in the post-Soviet region:

1. Which patterns of international collaboration have emerged and developed in former USSR countries during the post-Soviet era?
2. What are the changing roles of Russia and Western countries in this collaboration?

The purpose of this paper is to study the international scientific collaboration of post-Soviet countries and search for answers to these research questions. We analyze international collaboration of 15 post-Soviet countries in 1993-2018. First, we look at the dynamics of international collaboration in general publication output and its variation by quality and research fields. Then, we analyze how scientific collaboration has changed within the region and who is the main scientific partner of post-Soviet countries. And finally, using a fractional approach, we estimate the role of post-Soviet countries in collaboration with other countries in general output and high-quality segment.

2. Data and Methods

Our sample consists of 15 post-Soviet countries and their Web of Science (WoS)-indexed publications. WoS is chosen for its international scope and its stability in journal coverage (Moed, Markusova & Akoev, 2018). We used data about the total number of journal articles and reviews in 1993, 1997, 2003, 2008, 2013, and 2018. Data was attributed to countries' profiles in WoS (indexes SCI-expanded, SSCI and A&HCI, document types “article” and “review”). We also use data about the number of publications in the journals of the highest (Q1) and the lowest (Q4) quartiles according to their Journal Impact Factor (JIF).

In our paper, international scientific collaboration between countries is studied through publications. We consider an internationally co-authored work as publication which was prepared with the participation of two or more countries. We do not cut publications by the number of authors, so publications with one author and several country affiliations (solo publications) are also present in our dataset. Solo publications reflect a very specific type of collaboration between countries when transfer of knowledge between countries is provided by one person. This collaboration may be short term and an ineffective use of resources. If a country has a high share of this collaboration it may contain some risks (Matveeva & Ferligoj 2020). However, this collaboration may reflect some general tendency of collaboration between countries, for example the growth of academic mobility. In addition, it is hard to say that the impact of one author in solo publications on the national science of a country is very different from the impact of authors from other publications. For these reasons, we analyze separately the share of solo publications for each post-Soviet country and do not exclude it from the dataset.

For each country, we consider the total number of publications, the number of publications in Q1 and Q4 journals and in different research areas. Different research areas have their own specific of the research activity. For example, natural science research is often done using international

equipment and with an international team. Moreover, in Soviet science, natural sciences prevail (Graham 1993), so post-Soviet countries may continue work and collaborate with foreign colleagues in this area or develop other disciplines due to new international communication. We use OECD classification (<http://help.prod-incites.com/inCites2Live/filterValuesGroup/researchAreaSchema/oecdCategoryScheme/oecd.html>) to separate research areas and look at how international collaboration patterns of post-Soviet countries in different disciplines vary.

Besides disciplinary differences, scientific collaboration with other countries may vary by the quality of publications. High-quality work may need additional resources, which are easier to find in collaboration. With that, international knowledge exchange between scientists promotes increasing the quality of their work. Post-Soviet countries were isolated from Western science for a long time, so at the initial stage these countries may not be ready to collaborate with other countries on a high-quality level. In our work, we estimate the quality of publication using the JIF of the journal in which a paper was published. JIF quartiles are used as alternative indicators of quality (see Waltman (2016) for a review of using JIF for such purposes), although they should be used with caution (see Miranda & Garcia-Carpintero 2019 for a detailed review of advantages and drawbacks of such approach).

To delve deeper into the characteristics of collaboration and complement the standard indicators we employ two additional approaches, both of which could be viewed as variations of counting methods (see Gauffriau 2021 for a comprehensive literature review on this topic). In general, it is advised to use and compare different counting methods for comparisons between countries (Egghe, Rousseau & Van Hooydonk 2000; Moed 2006), and it is especially true for our case because of the clear limitations of simple metrics like “% of international papers” when comparing publications with widely different author and affiliation counts.

The first method we chose is fractional counting using institutional affiliations. We use address-level fractional country counting as a next-best to author-level country fractional counting (Waltman & van Eck 2015) for the reason of data availability. WoS has no author-affiliation links prior to 2009, so it is impossible to assign authors to countries for earlier papers, which are very important for us. Hence, we propose that the method of assigning different weights to countries mentioned in one paper is more informative than the simplest possible fractional counting when each country has $1/n$ share regardless of its authors and addresses. Using a script in Python, we parse and process affiliations (“C1” field in WoS data schema) and then count the affiliations of each country and divide them for each country by the total number of affiliations in the paper. Thus, a paper having addresses of Moscow State University, Saint Petersburg State University, Harvard University and Yerevan State University is processed into [Russia], [Russia], [USA], [Armenia], and Russia gets $1/4+1/4=1/2$, while USA and Armenia each get $1/4$. Naturally, this has a drawback of not taking into account the number of authors from each organization, but in our view such a counting method still has analytical value, especially for studying the relative participation of collaboration. We omit papers with >10 authors to focus on small- and medium scale projects, for which such data is more relevant (in the all sample the share of papers with 10 or more authors is 1.8% in 1993 and 11.3% in 2018). The share of papers with different numbers of authors by post-Soviet countries is presented in Fig. 1.1 in appendix.

The second counting method complements the first and is essentially a straight counting method (Gauffriau 2021) based on corresponding (reprint) address (“RP” field). This yields one country per paper. The idea is to capture the relative country roles using the fact that the corresponding author usually plays an important role in the paper. Their address usually indicates the main affiliation if he/she has several of them in different countries. If a country is mentioned in 100 papers but only 50% of them have its reprint address, it is essentially not the same as when this share is 75%, the latter indicating a bigger relative role (see relevant results for Brazil in (Grácio et al. 2020). For these reasons, we exclude papers with >10 authors.

3. Results

3.1. Basic bibliometric characteristics and the collaboration trends of the countries

Prior to presenting the results we have to acknowledge several important features of the surveyed countries, which should be taken into account. The Soviet Union occupied a huge territory from the Far East and Central Asia to Baltic Sea. Despite the union management system, the national republics of the USSR differed in many aspects: the size of territory, climate, culture and economic specialization. In the post-Soviet period, this difference among countries is also observed (Table 1A in appendix). Azerbaijan and post-Soviet countries from Central Asia demonstrate the growth of population from 1993 to 2018, while the population in all other countries decreased. According to available data, Baltic countries and Russia are the leaders in the number of researchers per million people. These countries and Belarus also have the highest expenditure on research, while post-Soviet countries from Central Asia have the lowest.

We analyze international collaboration through publication data. Post-Soviet countries have a large variation in publication output (Table 1). Expectedly, Russia has significantly more publications than other countries. With that, Baltic countries have the most number of publications per million people. Lithuania, Estonia and Armenia also have the most number of publications per capita (Chankseliani, Lovakov & Pisyakov 2021). Central Asia countries have the lowest publication outputs normalized per million people. Growth rates of publications also vary significantly by the countries, with drop and growth in different periods. In recent years, Turkmenistan, Moldova, and Ukraine demonstrate negative growth rates of publications. The opposite situation is in Kazakhstan (+128.4%), Azerbaijan (+76.4%), and Latvia (+61.1%). These countries have the highest values of growth rates. During the analyzed period, Turkmenistan and Tajikistan have the lowest number of publications. For some years the number of WoS-indexed publications from Turkmenistan was less than 10. This is a very small number to make credible judgments about collaboration configurations in these countries, apart from noting that these countries are almost absent from the international academic field.

Table 1. Publication output of post-Soviet countries in dynamics

	1993	1998	2003	2008	2013	2018
Total number of publications (articles & reviews)						
Baltic States						
Estonia	277	551	633	1090	1804	2223
Latvia	265	343	312	447	635	1023
Lithuania	198	423	665	2044	2054	2798
Caucasus						
Armenia	207	283	388	572	735	930
Azerbaijan	198	168	229	306	444	783
Georgia	209	210	234	354	552	859
Central Asia						
Kazakhstan	244	193	242	230	560	1279
Kyrgyzstan	38	34	27	63	103	157
Tajikistan	79	26	29	50	72	87
Turkmenistan	24	9	6	4	13	4
Uzbekistan	381	337	300	309	320	334
Eastern Europe						
Belarus	999	1195	985	1050	1078	1335
Moldova	205	165	196	229	255	231
Russia	22204	25827	25169	27252	29874	39761
Ukraine	3407	4156	3810	5049	4977	4792
Growth rate by year, %						
Baltic States						
Estonia	-	98.92	14.88	72.20	65.50	23.23
Latvia	-	29.43	-9.04	43.27	42.06	61.10
Lithuania	-	113.64	57.21	207.37	0.49	36.22
Caucasus						
Armenia	-	36.71	37.10	47.42	28.50	26.53
Azerbaijan	-	-15.15	36.31	33.62	45.10	76.35

Georgia	-	0.48	11.43	51.28	55.93	55.62
Central Asia						
Kazakhstan	-	-20.90	25.39	-4.96	143.48	128.39
Kyrgyzstan	-	-10.53	-20.59	133.33	63.49	52.43
Tajikistan	-	-67.09	11.54	72.41	44.00	20.83
Turkmenistan	-	-62.50	-33.33	-33.33	225.00	-69.23
Uzbekistan	-	-11.55	-10.98	3.00	3.56	4.38
Eastern Europe						
Belarus	-	19.62	-17.57	6.60	2.67	23.84
Moldova	-	-19.51	18.79	16.84	11.35	-9.41
Russia	-	16.32	-2.55	8.28	9.62	33.10
Ukraine	-	21.98	-8.33	32.52	-1.43	-3.72
Number of publications per million people						
Baltic States						
Estonia	185.39	397.50	461.80	815.20	1368.74	1681.57
Latvia	103.38	142.32	136.37	205.30	315.50	530.83
Lithuania	53.77	119.18	194.72	639.10	694.46	998.74
Caucasus						
Armenia	61.55	91.04	128.56	196.72	253.66	315.07
Azerbaijan	26.42	21.23	27.81	34.92	47.15	78.77
Georgia	42.56	49.49	59.21	91.99	148.48	230.51
Central Asia						
Kazakhstan	14.90	12.81	16.23	14.58	32.87	69.98
Kyrgyzstan	8.41	7.13	5.35	11.84	18.01	24.83
Tajikistan	14.12	4.31	4.43	6.93	8.93	9.56
Turkmenistan	5.98	2.04	1.29	0.81	2.42	0.68
Uzbekistan	17.36	14.01	11.73	11.32	10.58	10.13
Eastern Europe						
Belarus	97.57	118.68	100.54	110.20	113.88	140.77
Moldova	68.95	56.23	67.53	79.85	89.20	85.30

Russia	149.56	174.90	174.00	190.92	208.17	275.20
Ukraine	65.29	82.88	79.69	109.15	109.41	107.39

Most post-Soviet countries show increasing publication output. This growth coincides with general world tendency (Kumar & Asheulova 2011). Number of publications can be boosted by several interconnected mechanisms: the endogenous growth of national science based on economic growth, government policy linking paper counts with resource distribution and academic career promotion (Gingras 2020), and collaboration with researchers from other countries, although such a relation is complicated (He, Geng & Campbell-Hunt 2009).

Post-Soviet countries are included in global academic processes although these countries have their own features. In Fig.1 we compare the dynamics of international collaboration in post-Soviet countries with a global baseline. The global baseline shows the average share of international collaboration for all countries included in InCites dataset (<https://incites.help.clarivate.com/Content/Indicators-Handbook/ih-baselines.htm>). In all post-Soviet countries the share of international collaboration is higher than the world average. In all post-Soviet countries and in the world on average we observe the growth of collaboration between countries. Most post-Soviet countries have increased international collaboration faster than the world average growth rate. In 1993 Azerbaijan and Russia were close to world average values. Since 2008 Russia and Lithuania have differed from other post-Soviet countries: the share of international collaboration in these countries is significantly lower than for other former USSR countries.

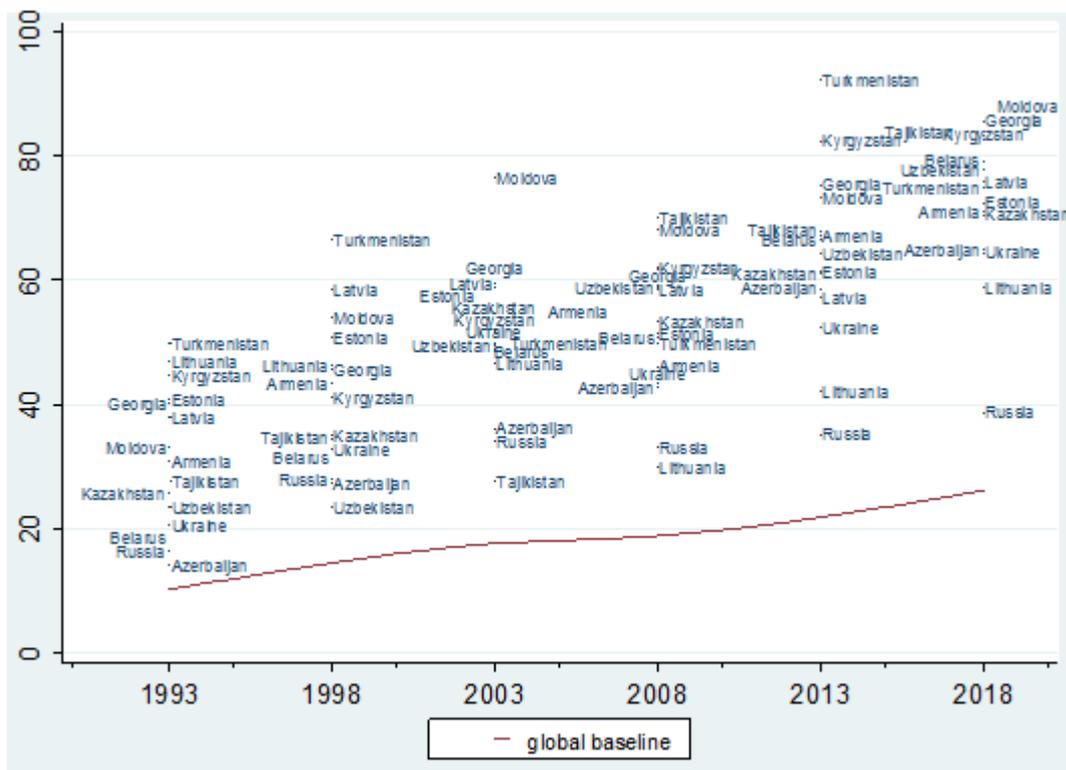


Fig. 1. International collaboration of post-Soviet countries and global trend

We observe that the variation of international collaboration between countries has increased (Fig. 2). From Fig. 2, 4, 7, 8, 9 we excluded Tajikistan and Turkmenistan due to its small number of publications. The results for these countries are presented in the text. In 1993, Azerbaijan, Russia, and Belarus had the lowest (less than 20%) share of internationally co-authored papers; the highest values were in Lithuania and Kyrgyzstan (about 50%). In 2018 Russia and Lithuania demonstrate the lowest values of international collaboration (40% and 60% respectively), the highest values are in Kyrgyzstan, Georgia, and Moldova (almost 90%). For the whole period, Russia's level of international collaboration increased. Lithuania demonstrates the opposite case, shifting from the highest share of international collaboration to the lowest. Tajikistan and Turkmenistan have also increased international collaboration in the observed period. For Tajikistan the share of papers in international co-authorship has increased from 27.85% to 85.06%; for Turkmenistan from 50% to 75% respectively.

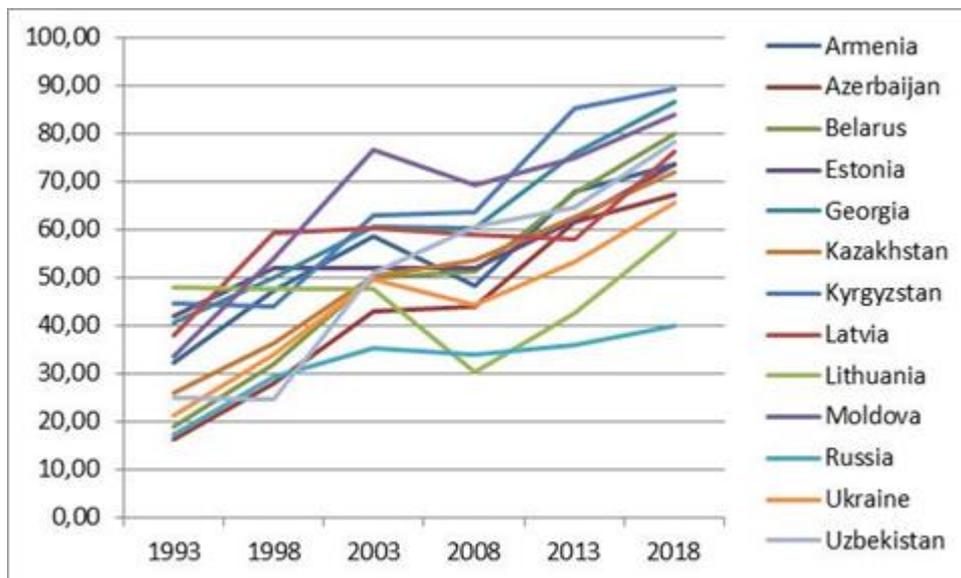


Fig. 2. Share of international collaboration by countries

Post-Soviet countries have a big variation in publication output and also in publication dynamics. Most countries significantly increased their publication output, although the number of publications from Moldova, Ukraine and Turkmenistan has decreased over the last five years. The share of international collaboration increased in all countries. Some countries with a smaller number of publications (e.g. Kyrgyzstan, Moldova, and Uzbekistan) have a higher share of international collaboration than countries with a bigger publication output, but we do not observe a strict dependence between the size of the country and the share of its international collaboration. In the next section we look in detail at how international collaboration of the countries differ in terms of the number of participating countries, research disciplines and the quality of publication output.

3.2. The kinds of international cooperation

Scientific collaboration has a different effect on participants depending on collaboration type (Leahey 2016). Expectedly, the impact of international collaboration on a country's publication output also depends on the type of collaboration and the role of the country in this collaboration. Country citation varies significantly between the number of countries, which participate in the work (Potter, Szomszor & Adams 2020). Generally and for large datasets it is observed that multi-country papers are cited more than papers prepared in one country. Such a positive collaboration

effect is naturally higher for countries with a small research capacity. The relative impact of a country in multi-country work can be lower than in papers with a small number of countries.

Most post-Soviet countries have increased multi-country collaboration when participating in papers mentioning 4 or more countries (Fig. 3). Until 2008, in almost all countries 2-country collaboration dominated. Since 2013 in Armenia, Georgia, Latvia and Estonia, multi-country collaboration has been prevalent, but it could have several reasons. Smaller countries rely more on collaboration due to the sheer size of their research systems and the lesser number of available local collaborators (Luukkonen et al 1993). Latvia and Estonia as EU countries have specific reasons to collaborate due to the collaborative nature of the Union itself and its funding programs (especially Framework programs). But for several countries, especially Armenia, bibliometric indicators are severely biased by one specific research type: high-energy physics mega collaborations, primarily those at CERN and especially the Large Hadron Collider, which started producing hundreds of papers in the best physics journals in 2011-2012 (Hallonsten & Cramer 2020). Such papers have hundreds or even thousands of coauthors from across the Globe.

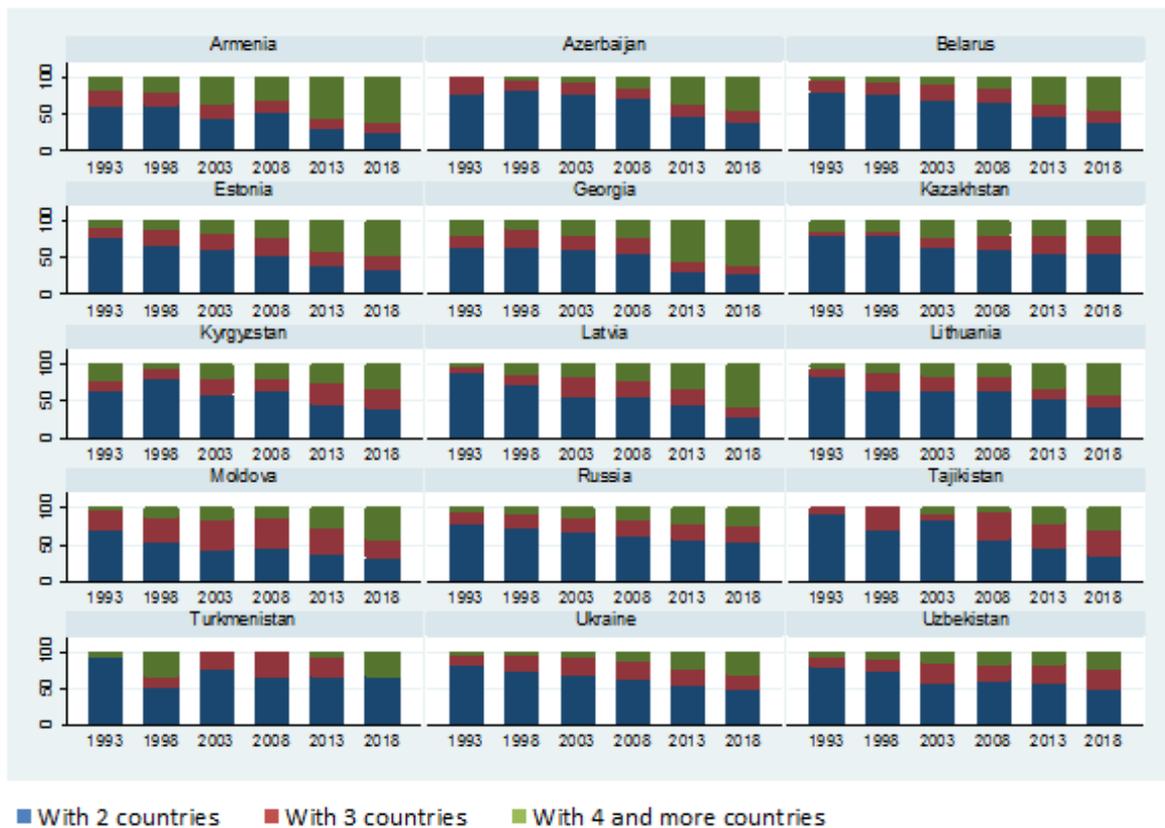


Fig. 3. Share of internationally co-authored publications with different numbers of countries

We also observe that there is a special type of collaboration between countries when one author works in several countries. In recent years, for most post-Soviet countries the share of these papers in international output is less than 2% (Fig.4). However, for Kyrgyzstan, Armenia and Azerbaijan this value is higher. One of the reasons which stimulate scientists to have several affiliations is finding and maintaining access to resources. A large foreign diaspora and policy measures based on bibliometrics, have also forced scientists to find additional affiliations (Hottenrott, Rose & Lawson 2021). In almost all analyzed years Kyrgyzstan, Armenia and Azerbaijan demonstrate a higher share of solo publications with multi-country affiliation than other post-Soviet countries. Thus this

situation is more likely to be explained by individual characteristics of the research system in these countries than by some policy measures or other shocks. Tajikistan and Turkmenistan have the highest share of solo publications with multi-country affiliation (about 33% in some years), but in absolute values it is a very small number of publications, so it is harder to interpret.

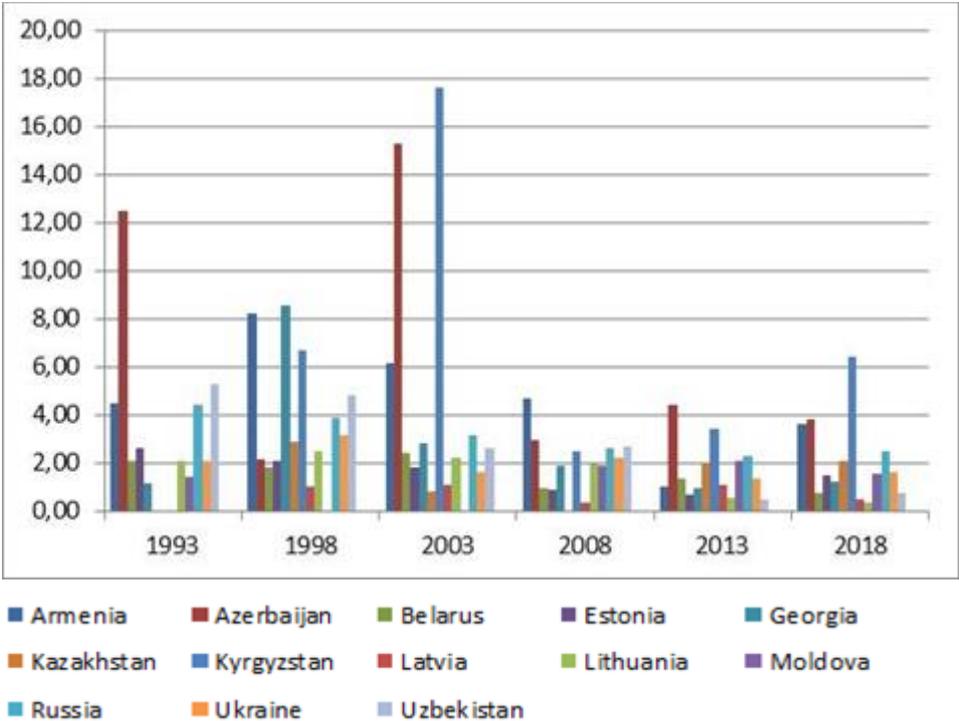


Fig. 4. Share of solo-publications with two or more countries

Next we look at how international collaboration of post-Soviet countries in different research disciplines differs. We analyze the share of publications written in co-authorship with other countries from the publication output of each discipline. Since post-Soviet countries have high variation in the share of international collaboration we present the median value of this parameter, calculated based on values of the 15 countries, the median is less sensitive to outliers. The highest shares of papers in international co-authorship are observed in the Medical & Health, Agriculture and Natural Science disciplines (Fig. 5). In recent years the share of international collaboration in these disciplines is over 70% in half of post-Soviet countries. Since 2003, international collaboration in Agriculture and Social disciplines has increased rapidly. We also observe stable growth of international collaboration in Humanities disciplines since 2003. Before 2003 most post-Soviet countries did not have collaboration with other countries in Humanities disciplines, in 2018 half of post-Soviet countries 20% of Humanities papers were written in co-authorship with other countries.

Share of international collaboration in different research areas also varies between post-Soviet countries (Fig. 6). For most countries, Natural sciences, Engineering & Technology and Medical & Health sciences are the areas with the greatest share of international collaboration. Tajikistan, Moldova and Turkmenistan do not have international collaboration in Humanities disciplines. In recent years, Uzbekistan, Kyrgyzstan, Armenia and Azerbaijan have developed international collaboration in the Humanities research area. During the analyzed period, Latvia had approximately equal share of papers in international co-authorship in all disciplines. When

comparing this country to the neighboring Lithuania, we see much lower values of international collaboration in many areas, especially in Humanities. This could be due to the uneven indexing of local journals: while Latvia has zero journals in Arts & Humanities Citation Index, Lithuania has three. So Latvian humanities scholars only have foreign titles, where it is natural to expect a higher rate of international collaboration.

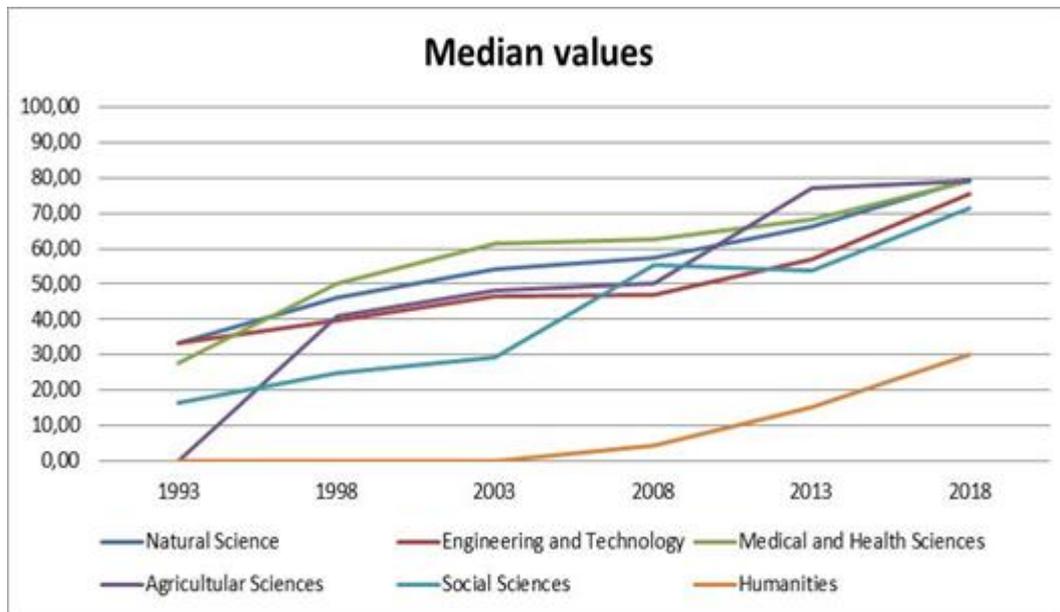


Fig. 5. Share of international collaboration by research areas (median values calculated based on values of the 15 countries)

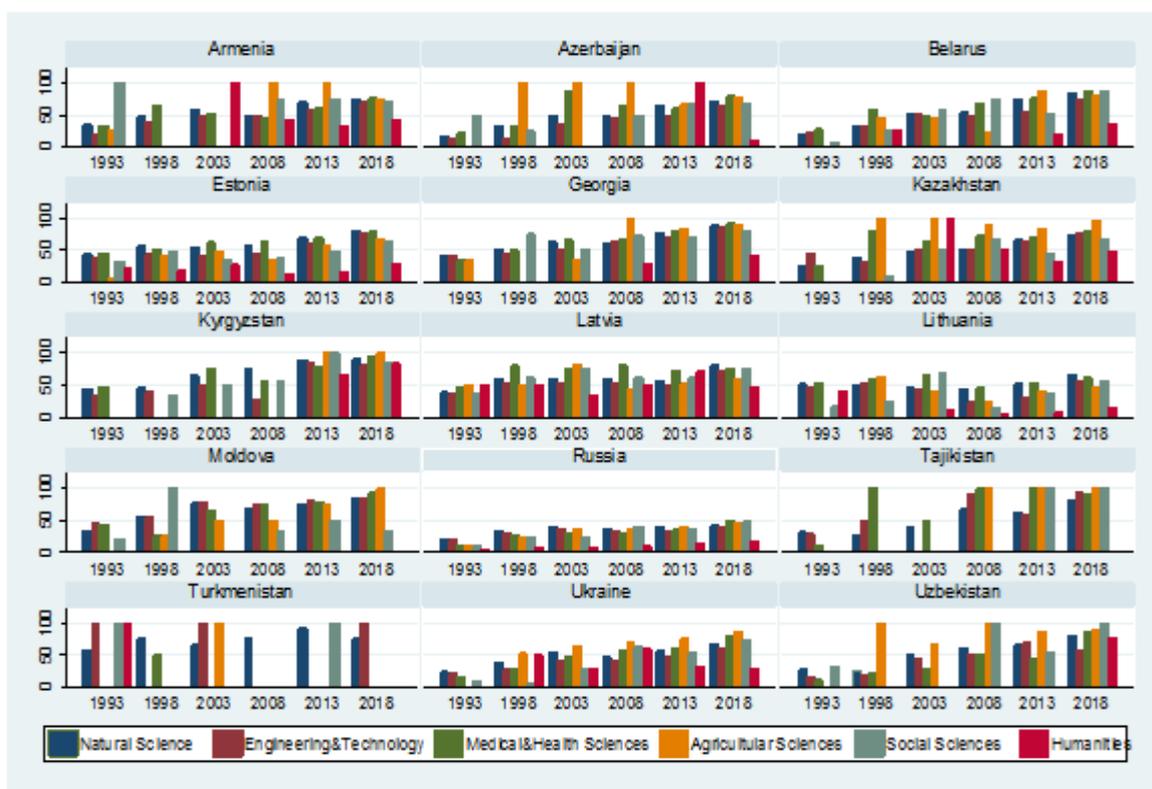


Fig. 6. Share of international collaboration by research areas

Papers of different quality may need different resources. High-quality publications require more people and equipment, so the share of international collaboration in these papers may be higher. For all post-Soviet countries the share of international collaboration in the Q1 journals is higher than in Q4 journals (Fig. 7). In 2018, in all post-Soviet countries more than 70% of publications in Q1 journals were written in co-authorship with foreign colleagues. Tajikistan, Turkmenistan, Uzbekistan and Moldova demonstrated the largest shares of international collaboration in Q1 journals. Share of international collaboration in the Q1 journals in Russia and Lithuania is lower than in other post-Soviet countries. Russia has the smallest share of publications with international co-authors in Q4 journals (less than 17% in all years). Kyrgyzstan and Moldova demonstrate the highest share of international collaboration in the Q4 journals.

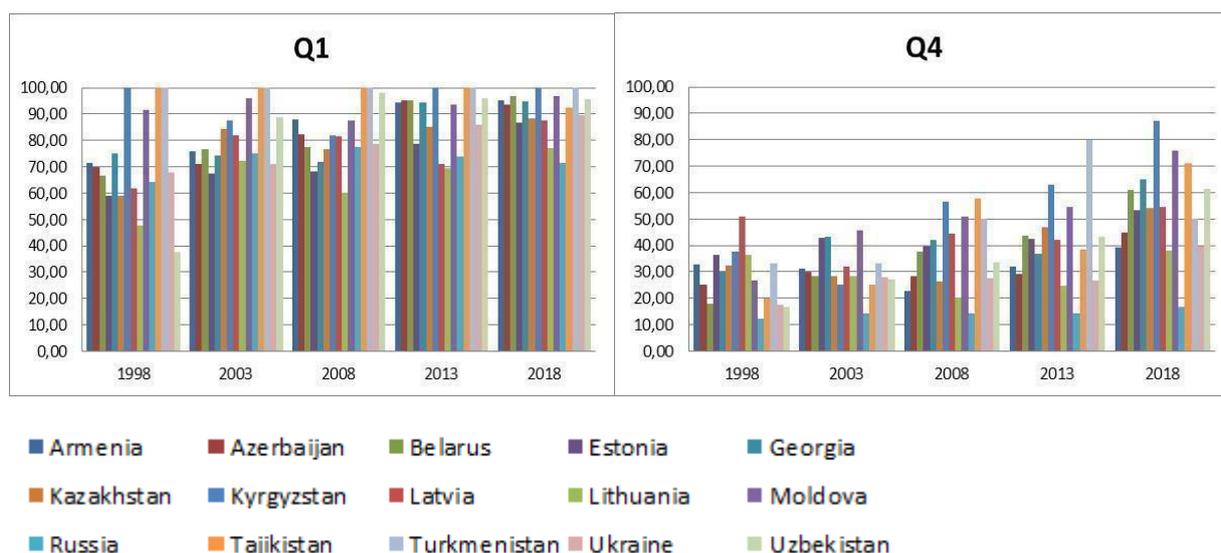


Fig. 7. Share of international collaboration in journals with different quartiles

These results show that the international collaboration patterns of post-Soviet countries have become more different over time. Many countries are moving to multi-country collaboration and intensifying international collaboration in new research areas. Some countries (e.g. Russia and Lithuania) have not significantly changed their collaboration patterns during this time. International collaboration may contain some risks, such as depleting a country's academic resources (see more in Leydesdorff & Wagner 2008), although it promotes experience exchange and growth in research skills, which may have a long positive effect on national science. Moreover, we observe that international collaboration is prolific for high-quality output. In other words, most of the high-quality post-Soviet papers are written in participation with foreign colleagues. In the next section we answer the question: is international collaboration of post-Soviet countries seen in a greater degree of collaboration inside the region or with Western countries.

3.3. Who collaborates with whom? Analysis of the main collaborators

After the collapse of the Soviet Union, post-Soviet countries on average collaborated with each other more often than with the countries outside the region. In 1993, the share of collaboration with the countries inside the region was about 40% for most post-Soviet countries, 73% for Kazakhstan and 53% for Uzbekistan (Fig. 8). Fig. 8 demonstrates the share of international collaboration with countries inside and outside the region in the total number of internationally co-authored

publications. Papers which were written together in co-authorship with countries both inside and outside the region are not presented in the figure.

In the following years almost all post-Soviet countries cut their scientific collaboration inside the region, although with different rates. Belarus and Kazakhstan reduced collaboration inside the region less than other post-Soviet countries. However, for these countries the share of collaboration with other post-Soviet countries is only about 20% of all internationally coauthored papers. Armenia, Latvia, Georgia, Belarus and Azerbaijan significantly intensified collaboration with countries outside the region. Fig.8 demonstrates that during the time collaboration inside the region flows to collaboration with other countries (see these countries in Table 2). Belarus demonstrates a unique case: this country keeps contacts inside the region and builds up collaboration with countries outside the region. This country demonstrates very high growth rates of international collaboration. Russia reveals the opposite situation: the share of collaboration with countries inside the region decreased while out-region collaboration did not increase significantly.

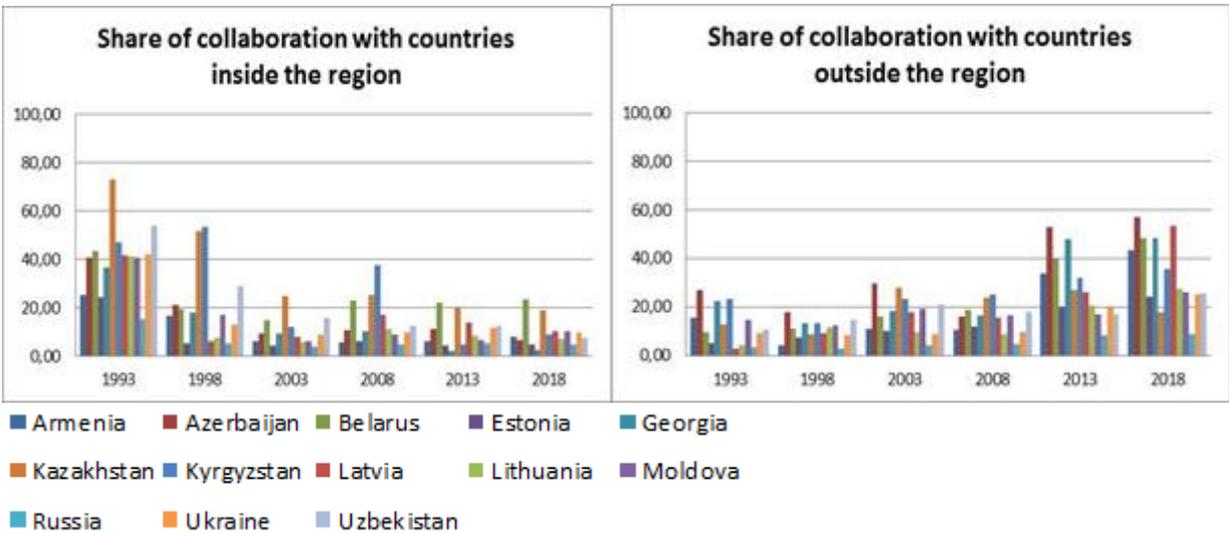


Fig. 8. Share of collaboration with countries inside and outside the region

Russia has the biggest publication output in the region, so the picture which we observe in Fig. 8 may reflect just collaboration with Russia. We analyze separately collaboration with Russia only and with Russia and other countries to see how the presence of Russia changed in the region. Many post-Soviet countries have decreased the share of joined papers with Russia (Fig. 9). We observe that collaboration dynamics inside the region are very similar with collaboration dynamics with Russia only. Collaboration with Russia and other countries did not significantly change in the period. Belarus has reduced the share of collaboration with Russia to a lesser extent. Kazakhstan has decreased the share of pure collaboration with Russia from 73.02% to 18.87%, but it is still a high value in comparison with other post-Soviet countries. Tajikistan and Turkmenistan have decreased collaboration with Russia. In 2013-2018, Armenia, Latvia and Georgia had the largest share of collaboration with Russia and other countries (about 50%). Thus, we observe that post-Soviet countries reduce their pure collaboration with Russia, but Russia still presents in collaboration when several countries participate.

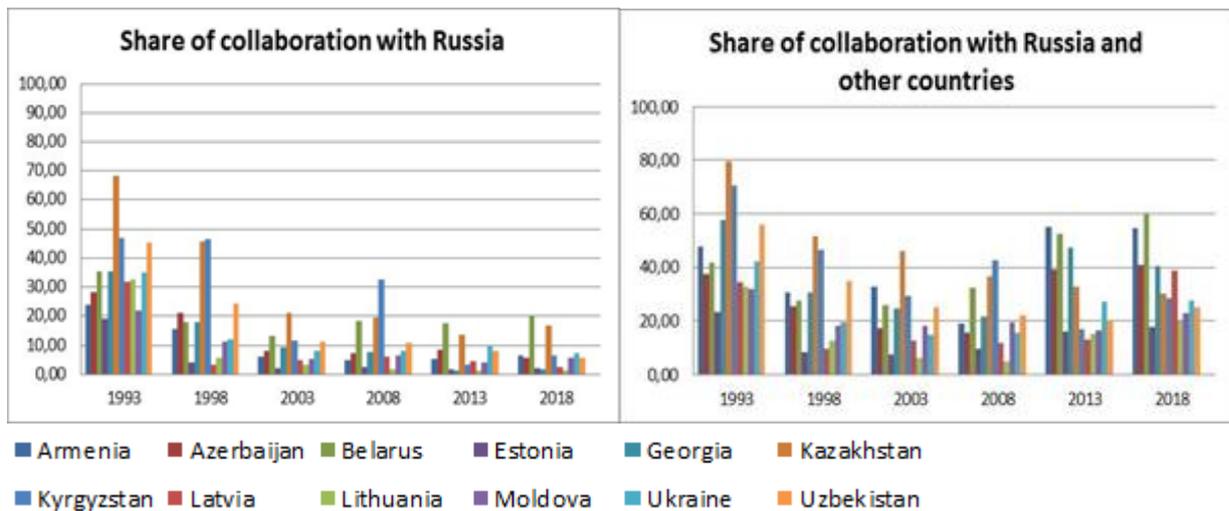


Fig. 9. Share of collaboration with Russia only and with Russia and other countries

Next we look at the main collaborators of post-Soviet countries. For each post-Soviet country, Table 2 shows the three countries with which the country has the most number of joint publications. In 1993, Russia was the main scientific partner for the other post-Soviet countries. In the following years, the share of collaboration with Russia decreased gradually for most post-Soviet countries. This drop in collaboration with Russia can be explained by the growth in collaboration with other countries. The Baltic countries have reduced active collaboration with Russia and other post-Soviet countries since 1998. During the period, the main collaborators of Russia were Germany, USA and France. We also observe these Western countries as the main collaborators of other post-Soviet countries. Territorial proximity in countries' scientific collaboration also takes place. Baltic countries often collaborate with Sweden and Finland; scientists from Azerbaijan and Turkmenistan actively collaborate with colleagues from Turkey, and scientists from Moldova with Romania.

Our results demonstrate that post-Soviet countries moved away from each other in the scientific field. Baltic countries turned to Western countries already in the first years after the collapse of the Soviet Union, other countries also have decreased collaboration inside the region. Russia still remains the main scientific partner for some post-Soviet countries, but its presence in the region has dropped significantly. With that, post-Soviet countries have increased significantly the share of international collaboration and this is mostly collaboration with Western Europe and the US. What is the role of post-Soviet countries in such collaboration we discover in the next section.

Table 2. The main collaborators of post-Soviet countries. Post-Soviet countries are bolded

	1993	1998	2003	2008	2013	2018
Baltic States						
Estonia	Russia	Sweden	Sweden	Finland	Finland	Germany
	Finland	Finland	Finland	USA	Germany	Finland
	Germany	Germany	Germany	Germany	USA	USA
Latvia	Russia	Germany	Germany	Germany	Germany	Germany
	Germany	Sweden	Sweden	England	Sweden	England
	Ukraine	USA	USA	USA	Finland	Lithuania

Lithuania	<i>Russia</i>	Sweden	USA	Germany	USA	Germany
	Germany	Germany	Germany	USA	Germany	USA
	Sweden	USA	Sweden	Poland	Poland	England
Caucasus						
Armenia	<i>Russia</i>	<i>Russia</i>	Germany	USA	<i>Russia</i>	<i>Russia</i>
	USA	Germany	<i>Russia</i>	Germany	Germany	USA
	Germany	USA	USA	France	USA	Germany
Azerbaijan	<i>Russia</i>	Turkey	Turkey	Turkey	Turkey	Turkey
	Turkey	<i>Russia</i>	<i>Russia</i>	USA	<i>Russia</i>	<i>Russia</i>
	<i>Ukraine</i>	Japan	USA	<i>Russia</i>	Germany	USA
Georgia	<i>Russia</i>	<i>Russia</i>	Germany	Germany	USA	USA
	Germany	Germany	<i>Russia</i>	<i>Russia</i>	Germany	Germany
	USA	USA	USA	USA	England	England
Central Asia						
Kazakhstan	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	USA	<i>Russia</i>
	Germany	USA	USA	USA	Germany	USA
	<i>Uzbekistan</i>	Germany	Germany	Germany	<i>Russia</i>	China
Kyrgyzstan	<i>Russia</i>	<i>Russia</i>	USA	<i>Russia</i>	Turkey	Germany
	<i>Ukraine</i>	USA	<i>Russia</i>	USA	Germany	<i>Russia</i>
	USA	<i>Uzbekistan</i>	Germany	Germany	<i>Russia</i>	China
Tajikistan	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	USA	<i>Russia</i>
	USA	England	USA	Pakistan	<i>Russia</i>	USA
	<i>Uzbekistan</i>	<i>Estonia</i>	Canada	England	Germany	Canada
Turkmenistan	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	Turkey	Turkey
	<i>Kazakhstan</i>	England	Turkey	Germany	<i>Azerbaijan</i>	Germany
	<i>Ukraine</i>	France	Israel	Turkey	England	<i>Kazakhstan</i>
Uzbekistan	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	Germany	<i>Russia</i>	<i>Russia</i>
	Japan	USA	USA	<i>Russia</i>	Germany	China
	<i>Ukraine</i>	Germany	Germany	USA	Spain	Germany
Eastern Europe						
Belarus	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>	<i>Russia</i>
	Germany	Germany	Germany	Germany	Germany	Germany
	<i>Ukraine</i>	USA	Poland	Poland	Poland	Poland
Moldova	<i>Russia</i>	Germany	USA	USA	Germany	Romania
	<i>Ukraine</i>	<i>Russia</i>	Germany	<i>Russia</i>	Romania	Germany
	Italy	Romania	<i>Russia</i>	France	<i>Russia</i>	<i>Russia</i>
Russia	USA	Germany	Germany	Germany	USA	USA
	Germany	USA	USA	USA	Germany	Germany
	France	France	France	France	France	France
Ukraine	<i>Russia</i>	<i>Russia</i>	Germany	Germany	<i>Russia</i>	<i>Russia</i>
	Germany	Germany	USA	USA	Germany	Poland
	USA	USA	<i>Russia</i>	<i>Russia</i>	USA	USA

3.4. Exploring patterns of collaboration by fractional counting

Fractional and straight counting methods allow us to further explore collaboration structure and dynamics for chosen countries. We present results starting with 1998 since in 1993 data about countries affiliations is not clean (there are many missed or unrecognized records), which significantly decreased the true values in 1993. We start by noting that for many countries the share of their affiliations in an average paper declines over the surveyed years (Fig.10), which is consistent with the growth of collaboration measured earlier in our paper. Notably, there are marked differences between countries, with Russia having the highest share which declines much more slowly. This is at least partly justified by the sheer size of Russian science which means many more local collaborators are available. Latvia occupies second place, but recently exhibits a dynamic more similar to the other smaller countries. On the other end of the spectrum lie Moldova, Turkmenistan, Tajikistan and Kyrgyzstan, countries with severely underfinanced and struggling academic systems.

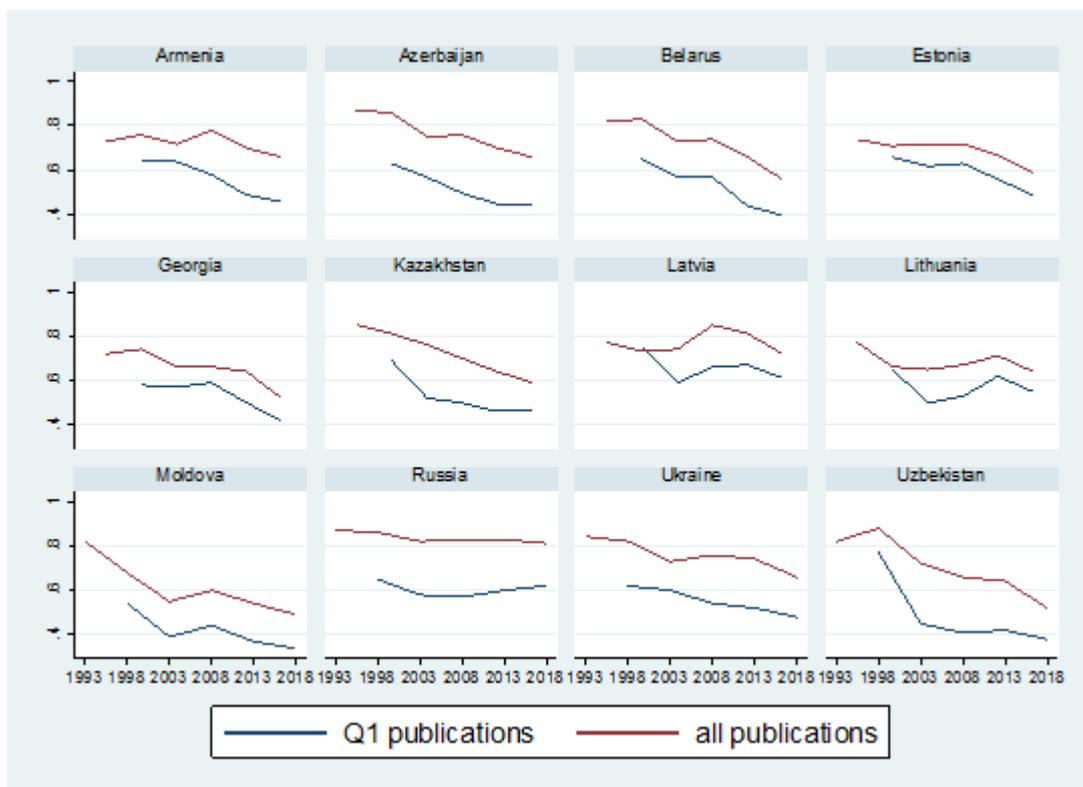


Fig. 10. Share of affiliations from each country in publications with 1-10 authors

This dynamic is also marked if we look at the subset of highly cited international journals (Fig. 11). Here the share of local affiliations is much lower for all the countries. Latvia is again a notable exception, as a country with relatively similar rates of local affiliations in both the “broad” and “highly cited” journal sets. The other Baltic states perform similarly, but still exhibit a downward trend. The only country with the rising share of local affiliations in Q1 journals is Russia.

Similar trends are seen when we look at the reprint addresses of the papers. If we consider all WoS journal papers regardless of JIFs, Russia turns out to be the only country which did not decrease the share of papers with reprint addresses among all papers with Russian affiliations in 1998-2018, with

roughly 80% of papers with 1-10 authors. For Moldova, Uzbekistan and Georgia this is 43-47% in 2018, and less than 40% for Tajikistan and Kyrgyzstan.

For the subset of highly cited journals (Fig.11) these ratios are again much lower. For Moldova, Uzbekistan, Tajikistan, Kyrgyzstan in 2018 less than 30% of papers in Q1 journals had their respective reprint addresses, with Turkmenistan having zero such publications. This could mean that when we speak about international publications in leading journals these countries' authors usually play a secondary role. On the other hand, Russia and Baltic States have much higher rates (65-68% for Lithuania and 50-55% for the rest), which suggests their authors' relatively important roles.

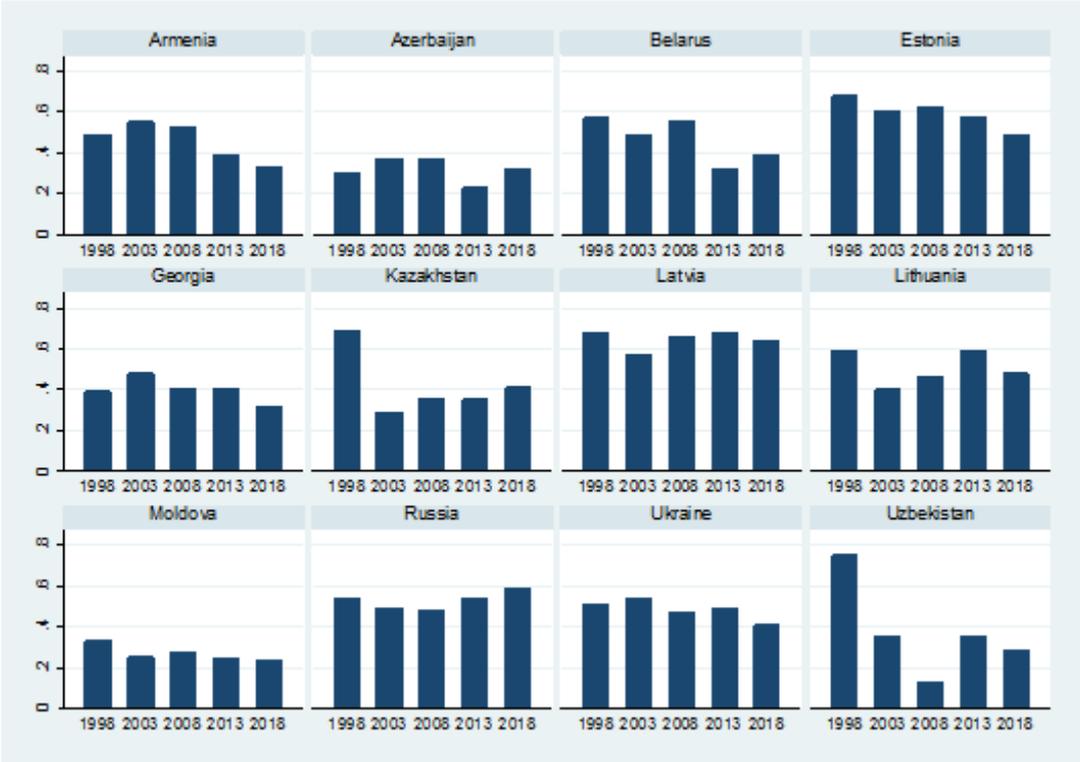


Fig. 11. Share of publications in Q1 journals with countries' own reprint addresses among all publications with these countries' affiliations

Reprint addresses also allow us to further investigate the directions of collaboration. Here again we utilize a subset of Q1 journals to focus on the internationally visible papers, and exclude papers with more than 10 authors, and then calculate for each country the shares of reprint addresses from (a) EU27 plus UK minus Baltic states (b) USA (c) Russia (Fig. 12).

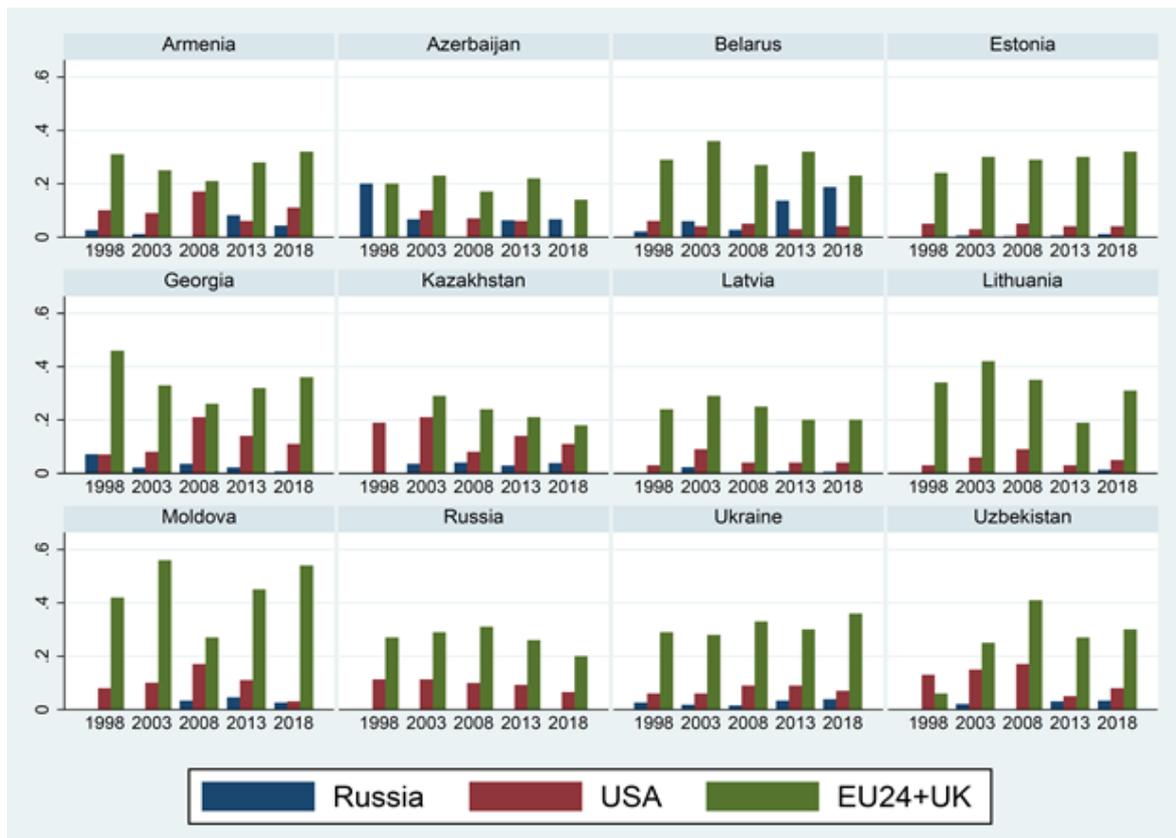


Fig. 12. Share of publications in Q1 journals with reprint authors from different countries

Moldova has the highest rate with 54% of its papers in 2018 having EU reprint addresses, with all others having much fewer, with Georgia, Ukraine and Armenia having the highest rates (32-36%), and Kazakhstan and Azerbaijan the lowest (14-18%). The USA has a much lower share of reprint addresses, which is slightly decreasing overall. Here the leaders are Kazakhstan, Armenia and Georgia with 11% in 2018, and Baltic states, Moldova and Belarus having 5% or less, and Azerbaijan having zero such papers in 2018. This country is collaborating mainly with Turkey which plays the most important role and consistently accounts for one fifth of reprint addresses in Azerbaijan papers in 1998-2018. Russia is not an important partner by this metric for all the surveyed countries during the whole period, with shares of less than 5% for all except Belarus. For the latter there is a marked increase in 2013 and 2018, jumping from 3% in 2008 to 14% and 19% respectively. This is consistent with geopolitical trends with Belarus being a close ally of Russia.

Results of fractional counting reveal that the growth of international collaboration activity of post-Soviet countries which we observe in previous chapters coincides with the decreasing role of these countries in such collaboration. The role of countries in high-quality publications is lower than in the general output and also has decreased for many countries. Russia and the Baltic countries (to a lesser degree) have not decreased their participation in international collaboration. the share of publications with reprint authors from post-Soviet countries decreased to a lesser degree than the share of affiliations from each country. This means that scientists from these countries still initiate and provide scientific work but with a larger number of foreign colleagues. In publications, which post-Soviet countries participate in, reprint-authors from European countries present more often, scientists from Russia are represented less.

4. Conclusion

Our analysis shows that after the collapse of the Soviet Union, post-Soviet countries significantly changed the patterns of international collaboration, and these changes were country-specific. For the last three decades post-Soviet countries actively intensified scientific collaboration with other countries, eliminating the scientific isolation of Soviet science (Schott 1992). With that, the share of international collaboration in post-Soviet countries is higher than average global values. Russia and Lithuania demonstrate the lowest share of international collaboration; Kyrgyzstan, Georgia and Moldova have the highest values. This could be interpreted as broadly in line with both older and recent research (summarized in Chinchilla-Rodrigues, Sugimoto & Larivière 2019) stressing the inverse relation between a country's size, scientific capacity and expenditures on R&D on one hand, and the share of internationally co-authored papers on the other. The quality of scientific infrastructure and the amount of various forms of capital needed for academic work are much higher in Baltic states and Russia than in other parts of the former USSR.

We observe that the collaboration patterns of post-Soviet countries differ by the number of participating countries. Many post-Soviet countries increased the share of papers, when 4 or more countries participated. In these works, the impact of each country is lower than in papers with a small number of countries, although this collaboration also gives an opportunity to be closer to world knowledge. The growth of multi-country collaboration can even be a specific form of international collaboration, when one group of scientists from a country actively participate in huge international research projects and the other forms of collaboration are less pronounced. In 2018, in Armenia, Georgia, Latvia and Estonia multi-country collaboration is prevalent, at the same time Russia, Kazakhstan and Lithuania more often collaborate with a small number of countries.

Post-Soviet countries demonstrate relative similarity in the quality distribution of international output. In all countries, the share of international collaboration is much higher in Q1 publications than in Q4. In 2018, in all post-Soviet countries more than 70% of Q1 publications were written in co-authorship with international colleagues. International collaboration in the Q4 segment has also increased in all post-Soviet countries except Russia. These results coincide with the findings that international collaboration is prolific in high-quality output (Matveeva & Ferligoj 2020; Ni & An 2018).

International collaboration in different disciplines is country-specific, but there are general tendencies. For most post-Soviet countries, Natural sciences, Engineering & Technology and Medical & Health sciences are the areas with the greatest share of international collaboration. We also observe stable growth of international collaboration in Humanities disciplines since 2003, although the growth rates of international collaboration coincide with the growth rates in other disciplines.

In the observed period, post-Soviet countries decreased collaboration with each other, while collaboration with countries outside the region has increased. Western European countries and the US are the main collaborators of post-Soviet countries nowadays, while territorial or cultural similarities are also present: Baltic countries actively collaborate with Sweden and Finland, Azerbaijan with Turkey, Kazakhstan and Kyrgyzstan with China. With that, despite the growing

research activity of China, we did not observe considerable participation of China in the research activity of post-Soviet countries.

The role of Russia in post-Soviet research output decreased. For many post-Soviet countries scientific collaboration with Russia decreased, only Belarus and to a lesser degree Kazakhstan and Ukraine kept research contact with Russia. While the relative role of Russia as a partner is decreasing for all the former USSR nations, the dynamics differ a lot, and tend to be aligned with broader geopolitical and foreign affairs agenda. Thus, Belarus and Kazakhstan, which collaborate with Russia most closely including via the Eurasian Customs Union, exhibit strongest ties and collaborate more directly (with fewer co-authors from non-exUSSR countries), the Baltic states show the opposite trend, and Georgia and Ukraine following in their steps after severe diplomatic rows in 2000s-2010s, and in Azerbaijan, Russia is displaced by Turkey.

Fractional counting lets us look at the composition of research teams, and corroborates the increasing trend of moving away from bilateral collaboration to multinational, often EU and US-led. Such an approach reveals that for the vast majority of ex-Soviet countries direct collaboration with Russia in papers published in highly cited journals has been virtually non-existent since the 1990s. This suggests that their collaboration before the dissolution of the USSR was low and in effect there was no unified Soviet research system (Rabkin & Mirskaya 1993). Consequently, the EU quickly emerged as the leading partner for almost all the studied countries, and currently leads the international collaboration in the former USSR area. Thereby we confirm the hypothesis by Thomas Schott almost thirty years ago (Schott 1992), that in future post-Soviet countries are more likely to be integrated with European countries than with American science.

Our work is based on data about countries' publications, so we do not take into account collaborations which are out of the surveyed bibliometric dataset. This limitation is acute especially for Turkmenistan and Tajikistan, which have very poor coverage in WoS. In addition to full counting, we use fractional counting of a country's affiliation and straight counting via reprint authors to estimate the role of the countries in international collaboration. However, all these variables and methods may not reflect the true impact of each country in a published work due to the complexity of real-world collaboration.

Still, we can reasonably state that in the most visible part of knowledge production in STEM areas - WoS-indexed journals - scientific collaboration with other countries plays an important and growing role in post-Soviet countries' research production. A significant part of the publication output of many post-Soviet countries is written in co-authorship with international colleagues. There are several reasons which can explain the growing tendency of international collaboration in post-Soviet countries. First, the weak research capacity in many post-Soviet countries may push scientists to find resources in collaboration. Second, during the transition period many scientists emigrated from post-Soviet countries (Ganguli 2014), thereby forming a research diaspora in foreign institutions. The strong research diaspora may influence international research contacts of post-Soviet countries. And finally, there is a global tendency of science internationalization (Leydesdorff & Wagner 2008), which we also can observe in post-Soviet countries.

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Appendix

Fig. 1.1. Share of publications with different number of authors

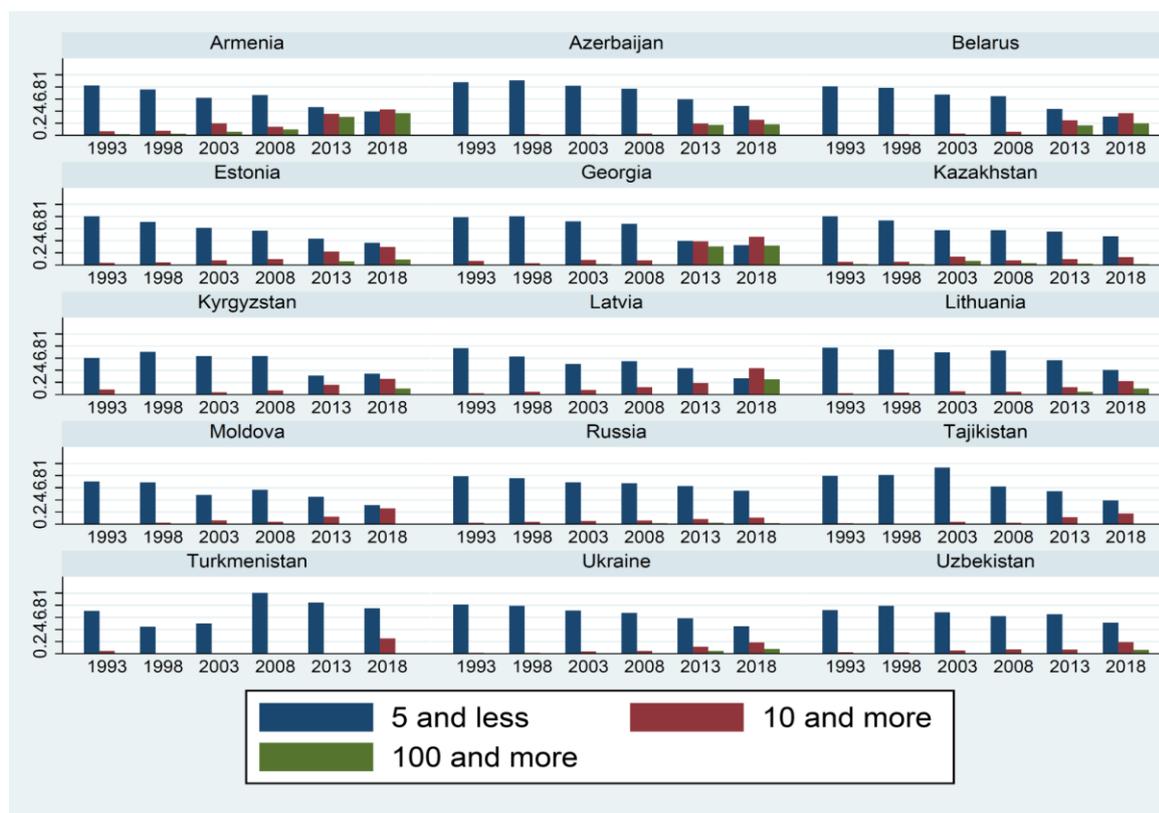


Table 1A. Descriptive statistics of post-Soviet countries¹

	1993	1998	2003	2008	2013	2018
Population, total						
Baltic States						
Estonia	1494128	1386156	1370720	1337090	1317997	1321977
Latvia	2563290	2410019	2287955	2177322	2012647	1927174
Lithuania	3682613	3549331	3415213	3198231	2957689	2801543
Caucasus						
Armenia	3363111	3108691	3017938	2907615	2897593	2951741
Azerbaijan	7495000	7913000	8234100	8763400	9416801	9939771
Georgia	4911100	4243607	3951736	3848449	3717668	3726549
Central Asia						
Kazakhstan	16380672	15071640	14909019	15776938	17035551	18276452
Kyrgyzstan	4516700	4769000	5043300	5318700	5719600	6322800
Tajikistan	5593317	6027395	6541550	7209924	8059782	9100847
Turkmenistan	4010789	4413477	4655752	4935765	5366376	5850902
Uzbekistan	21942000	24051000	25567650	27302800	30243200	32956100
Eastern Europe						
Belarus	10239000	10069000	9796749	9527985	9465997	9483499
Moldova	2973114	2934339	2902320	2867964	2858692	2708214
Russia	148458777	147670784	144648618	142742366	143506995	144477859
Ukraine	52179200	50144500	47812949	46258189	45489648	44622518
Researchers in R&D (per million people)						
Baltic States						
Estonia	..	2117,54	2197,52	2969,24	3341,01	3755,33
Latvia	..	1052,03	1389,08	2012,66	1772,65	1792,10
Lithuania	..	2372,90	1934,77	2624,76	2843,86	3190,70
Caucasus						
Armenia	..	..	..	..	..	..
Azerbaijan	..	..	..	..	..	..
Georgia	..	..	..	..	566,35	1463,77
Central Asia						
Kazakhstan	..	..	..	376,49	737,22	666,94
Kyrgyzstan	..	..	..	..	..	..
Tajikistan	..	..	..	..	..	..
Turkmenistan	..	..	..	..	..	..
Uzbekistan	..	..	588,33	580,41	507,04	476,18
Eastern Europe						
Belarus	..	..	..	..	..	..
Moldova	..	..	758,71	822,14	737,29	696,08
Russia	..	3342,10	3370,96	3149,86	3052,69	2784,33
Ukraine	..	..	..	1428,29	1162,05	988,08

¹ According to <https://data.worldbank.org/>

Research and development expenditure (% of GDP)						
Baltic States						
Estonia	..	0,57	0,76	1,25	1,71	1,40
Latvia	..	0,38	0,36	0,58	0,61	0,64
Lithuania	..	0,54	0,66	0,79	0,95	0,94
Caucasus						
Armenia	..	0,23	0,32	0,22	0,22	0,19
Azerbaijan	..	0,42	0,32	0,17	0,21	0,18
Georgia	..	0,35	0,22	..	0,08	0,28
Central Asia						
Kazakhstan	..	0,22	0,25	0,22	0,17	0,12
Kyrgyzstan	..	0,21	0,22	0,19	0,15	0,10
Tajikistan	..	..	0,07	0,07	0,12	0,10
Turkmenistan	..	..	..	..	..	..
Uzbekistan	..	..	0,27	0,19	0,16	0,13
Eastern Europe						
Belarus	..	0,71	0,61	0,74	0,65	0,60
Moldova	..	..	0,32	0,53	0,30	0,25
Russia	..	0,95	1,29	1,04	1,03	0,98
Ukraine	..	1,07	1,11	0,85	0,76	0,47