War and Science in Ukraine *

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Abstract

We discuss the impacts of the Russian invasion on Ukrainian science. Using newly collected data, we show that the war has already had significant effects: papers produced by Ukrainian scientists have declined by 20-30%, approximately 5% of the most prolific scientists are publishing with a foreign affiliation, 22% of top universities have faced destruction of physical capital, and international collaborations with Russian scientists have declined by about 40%. Drawing on the economics of science and innovation literature, we highlight three main channels through which wars and crises impact science: 1) the loss of human capital, 2) the destruction of physical capital, and 3) reductions in international scientific cooperation. The data and lessons from the literature indicate the need for effective measures to mitigate the shocks to human capital and resources to rebuild destroyed universities during reconstruction efforts. The evidence on the long-run effects of physical capital destruction from the literature suggests that shocks to physical capital can be remedied more easily than shocks to human capital. Thus, we highlight that policies should be particularly focused on supporting scientists to continue in the research sector and to return to Ukraine after the war has ended.

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1 Introduction

Science in Ukraine has a rich history and a well-developed scientific infrastructure with numerous research institutions and universities. On February 24, 2022, Russian troops started a full-scale invasion of Ukraine, which disrupted ordinary life and also had a significant impact on the country's universities and research institutes. The conflict disrupted the normal functioning of these institutions, and many scientists have been forced to relocate to other parts of Ukraine or even abroad.

In this article, we present new facts on the impact of the war on Ukrainian science. We then draw on the economics of science and innovation literature on war and other crises to point to the channels through which science is affected by war and conflict and discuss potentially effective ways to mitigate its negative impact on science and to aid reconstruction after the end of the war.

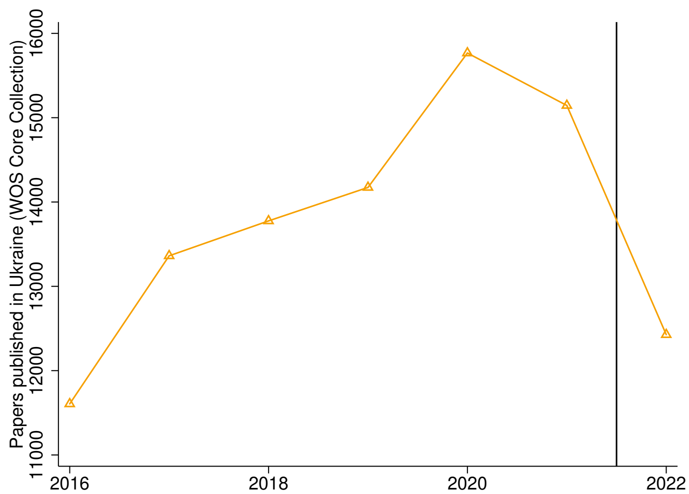
Only in retrospect will we be able to fully evaluate the effects of the war on Ukrainian science. Nevertheless, is becoming clear that the conflict has already had a significant impact on the country's scientific community. To study this medium-run impact, we collect data from *Clarivate Web of Science* and other sources. These data allow us to explore the impacts of the war on scientific production, the emigration of Ukrainian scientists, the destruction of physical capital in Ukrainian universities, and changes in international collaboration patterns of Ukrainian scientists.

Our newly collected data indicate that between 2021 and 2022 the number of papers produced by Ukrainian scientists already declined by 20-30 percent (see Figure 1). As scientific papers tend to be published with significant delays, and as the first two months of 2022 were not yet affected by the war, the decline shown in Figure 1 likely underestimates the actual effects of the war on Ukrainian scientific production.

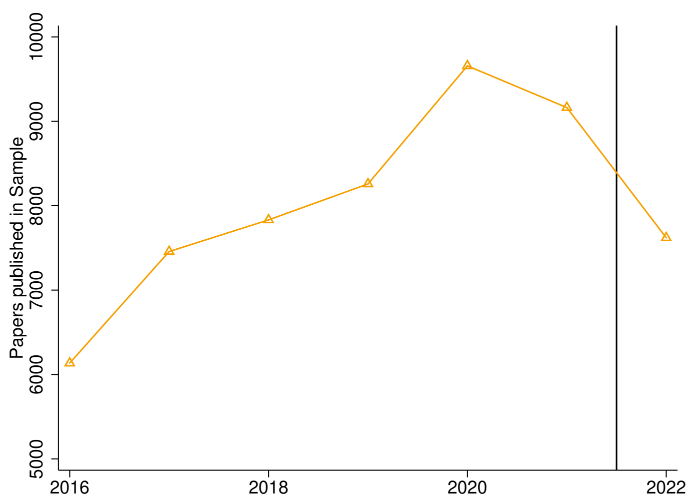
This decline in scientific production may be driven by a number of channels. First, the war has had a devastating effect on human capital, i.e., the scientists carrying out research in universities and laboratories. Many scientists have been forced to flee their homes and relocate to other parts of Ukraine or even abroad. Others have joined the army to fight in the war or were directly killed in the war. Second, the war may have affected physical capital as classrooms, laboratories, libraries, and other essential facilities have been damaged or destroyed by bombings, shelling, and other forms of violence. War-related power outages may have interrupted computers and experiments

Figure 1: Number of Publications by Ukrainian Scientists

(a) All Scientists



(b) Scientists in Top 100 Universities



Notes: The figure shows the total number of papers by Ukrainian scientists in the Web of Science. Papers with at least one coauthor affiliated with a Ukrainian research institution are counted. In panel (a), we report papers from any Ukrainian institution. In panel (b), we report papers with at least one coauthor affiliated with a top 100 Ukrainian university as measured by the Webometrics Ranking of World Universities by the CSIC Cybermetrics Lab.

and may have thus reduced the effectiveness of existing physical capital[1] Third, the war

[1] 40% of the energy system was reportedly damaged by January 2023: https://www.reuters.com/business/energy/ukraine-introduces-emergency-power-cuts-east-southeast-

has also hindered the exchange of scientific knowledge and ideas, as travel restrictions and the general insecurity in the country have made it more difficult for researchers to attend conferences, seminars, and travel to work with coauthors.

The patterns from the available data so far on the short run-impacts are quite are consistent with prior literature on the longer-run impacts of war and crises showing that shocks to physical capital can be remedied more easily than shocks to human capital. This suggests that there are substantive insights to be had already about Ukraine's trajectory, challenges, and need for interventions. In the rest of this article, we discuss the likely consequences of the shocks to human capital, physical capital, and to international collaborations by examining new data and by drawing on findings in the economics of science and innovation literature.

2 War and Human Capital

As highlighted above, the war in Ukraine has already disrupted the lives of scientists in Ukrainian research institutions and universities. Many had to flee their homes, relocate to other parts of Ukraine or even abroad, or join the army.

Even in peacetime, it is challenging to measure cross-country migration rates. In conflict situations, it is even more difficult to systematically measure relocations. Despite these challenges, a number of efforts have tried to estimate emigration rates among scientists from Ukraine. The Ukrainian Ministry of Science and Education estimates that approximately 6,000 of *all* 60,000 researchers, or 10%, left Ukraine due to the war (Irwin 2023).[2] De Rassenfosse et al. (2023) report an emigration rate of 18.9% among a sample of scientists that they surveyed in early 2023. A few surveys have focused on Ukrainian academics who emigrated after the onset of the war. For example, Maryl et al. (2022) used an open call and snowball sampling approach to survey 619 emigrants.[3] These surveys indicate that female scientists were more likely to emigrate and that many continue to work for a Ukrainian institution even though they are abroad.[4]

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[2]This estimate includes scientific support staff and junior researchers.

[3]With an open call approach, the researchers circulated and posted the survey link and did not try to make the sample representative of the population of scientists. Snowball sampling is a non-probability sampling method where new respondents are recruited by other respondents to form the sample.

[4]Similarly, De Rassenfosse et al. (2023) find that 74.6% of their survey respondents who had emigrated were women.

These surveys suggest that the war has already resulted in a large emigration wave from Ukrainian universities. Such survey-based estimates may, however, suffer from selection bias. Those who respond to surveys may not be random and, hence, survey-based emigration rates may either over or underestimate true emigration rates.

2.1 New Data on International Migration of Ukrainian Scientists

To overcome some of these challenges and to provide additional measures of emigration rates we collect data for two samples of Ukrainian academics. First, we collect data on 535 elite Ukrainian scientists who were working in the top 100 Ukrainian research institutions prior to 2022. Second, we collect data on all 58,139 scientists with an ORCID ID who reported an Ukrainian affiliation in 2021.[5] These two datasets enable us to provide a first glimpse at the international migration of Ukrainian scientists based on publication data and affiliation data from ORCID.

New Evidence on Emigration Rates Among Elite Scientists

To obtain our sample of elite scientists, we focus on the top 100 Ukrainian institutions, as measured by the Webometrics Ranking of World Universities by the CSIC Cybermetrics Lab.[6] We then collect information on the 10 to 20 highest-ranked academics in each of these 100 institutions if they published at least one paper in 2021.[7] We then classify scientists to have emigrated if they published a paper in 2022 with a non-Ukrainian affiliation. Of course, this may underestimate the extent of international migration because migrants may not yet have published with a foreign affiliation. Alternatively, it may overestimate overall emigration rates because elite scientists have higher emigration probabilities in general but also in conflict situations (e.g., Becker et al. 2021).

In our data, 4.7 percent of these elite scientists have already emigrated between 2021 and 2022 (see Table 1, Panel B). Emigration rates among elite Ukrainian scientists

[5]ORCID stands for Open Researcher and Contributor ID and is a unique and persistent identifier of researchers. The ID is created and maintained by the researchers themselves and includes affiliation information.

[6]https://www.webometrics.info/en/Europe/Ukraine

[7]For the top 30 universities, we collect at most 20 academics, for the universities ranked 31-100 we collect at most 10 scientists. Because some of the top 100 institutions do not appear in the *Web of Science* and because many of the top 100 institutions have fewer than 10 researchers with at least one paper in 2021, the total number of scientists in this sample is 535.

Table 1: Summary Statistics Ukrainian Universities

Panel A: University Level Data	
Number of universities	100
Percent with destruction	22
Percent relocated	5
Number of papers in 2021	9,163
Number of papers in 2022	7,620
Panel B: Scientist Level Data	
Number of scientists	535
Percent female	34,81
Percent emigrated	4,67
Panel C: Orcid Data	
Number of scientists	58,139
Percent female	56,07
Percent emigrated	0,20

Notes: The table reports summary statistics on universities and elite scientists. Panel A reports data for the top 100 Ukrainian universities. Panel B reports data for the 535 elite scientists from these top 100 universities. Panel C reports data for the 58,139 with an ORCID ID who reported a Ukrainian affiliation in 2021.

may, as yet, be relatively low for multiple reasons. First, since the imposition of martial law, men between 18 and 60 have been prohibited from leaving the country. Second, finding an attractive academic position abroad is difficult to organize in such a short time period, even for elite scientists. Third, Ukrainian scientists may feel a strong sense of attachment to their home country and culture, which could deter them from leaving, and they may join military effort. They may also feel a sense of responsibility to contribute to the scientific development of their country, especially during challenging times.

New Evidence on Emigration Rates Among Ukrainian Scientists with an ORCID ID

To complement the analysis of elite scientists with a broad sample of Ukrainian researchers, we analyze emigration patterns among researchers with an ORCID ID who reported a Ukrainian affiliation in 2021. There are no restrictions in obtaining ORCID

IDs. As a result, these data include professors at all levels of seniority, but also junior researchers such as PhD or Masters students, and company-based researchers.

As researchers can update their profile on ORCID the data may, in principle, be used to measure international migration of scientists (see, for example Bohannon 2017). At the time of writing, the newest available data from ORCID report affiliations for October 2022. This means that we can only measure very fast migration responses to the outbreak of the war.

In the ORCID data, 0.2 percent of researchers had emigrated by October 2022 (see Table 1, Panel C). This suggests that at this broad sample of researchers, emigration rates were, as yet, quite low. Of course, as many of these researchers were quite young and/or worked in companies they have fewer opportunities to find employment in a science-related job abroad.

Discussion and Comparison to Survey-Based Emigration Rates

The emigration rates in the two datasets are, as yet, relatively low. Our data may understate true emigration rates for various reasons. First, many scientists kept Ukrainian affiliations even when they moved abroad. If they continue to publish using only their Ukrainian affiliation, or if they do not update their ORCID profile to account for double affiliations, we would not observe that they have moved abroad. Second, in the elite scientist sample, we would only observe them with a foreign affiliation if they published a paper with the new affiliation.[8]

It is, thus, difficult to get an accurate picture of short-term emigration rates among Ukrainian scientists. Whether true emigration rates are closer to the survey-based estimates or to the estimates from our data is difficult to evaluate. Clearly, more representative, comprehensive, and longer-run data will have to be collected to measure the ultimate effect of the war on the scientific human capital stock in Ukraine.

[8] To get a better sense of such underestimation, we randomly sample 100 of the 535 elite scientists and searched the pre-print repository arXiv.org. Among the sample of 100 elite scientists, only two published a pre-print with a foreign affiliation until April 2023. We had already identified them as emigrants based on the paper-level data.

2.2 The Effect of War and Conflict on Scientific Human Capital

The Effect of War-Induced Migration on Scientific Human Capital

The previous literature highlights that war, conflict, and economic turmoil can cause large emigration flows of academics. Over the course of history, such episodes have, for example, caused large emigration waves of Jewish academics from Nazi Germany and from countries that were occupied by German troops during the Second World War (Waldinger, 2012; Becker et al. 2021). Similarly, thousands of Russian, Ukrainian and other formerly Soviet academics emigrated abroad after the collapse of the Soviet Union (e.g., Borjas and Doran, 2012; Ganguli, 2017).

The literature has documented that emigration rates are exacerbated because of network effects. Once the first group of emigrants has settled in their new destination, they attract other researchers from the professional network in their home country to their location (e.g., Becker et al., 2021; Ganguli, 2015). Because of these network effects, short-run increases in emigration rates can affect brain-drain in the long-run.

Emigration waves often have detrimental effects on universities in sending countries. In Germany and Austria, universities that lost more Jewish scientists because of Nazi persecutions did not recover for at least half a century (Waldinger, 2016).[9]

Previous research has also highlighted that one of the major effects of such emigration waves is the impact on young researchers. The resulting shortage of experienced mentors and role models for young researchers can have significant effects on their career outcomes and reduce the number of young people who enter scientific professions. The emigration of Jewish scientists in Nazi Germany, for example, reduced career opportunities of Ph.D. students in departments where high-quality mathematicians were dismissed (Waldinger, 2010). Similarly, the emigration of Soviet scientists after the collapse significantly harmed the careers of Russian Ph.D. students (Borjas and Doran, 2015; Ganguli, 2014).

Because scientists often permanently settle in their new destinations (e.g., Becker et al., 2021) or permanently leave science, the literature has documented significant and very long-lasting effects of losing scientific human capital in war and conflict situations.

[9]Other research has shown the mirror image of such effects: gaining leading researchers can lead to long-term positive gains (Agrawal et al., 2017).

Direct effects of War on Scientific Human Capital

In addition to emigration to foreign destinations, war and turmoil also affect scientific human capital through other channels. Researchers may join the war effort (e.g., Iaria et al., 2018) or be displaced within the country. Moreover, the psychological toll of war can have negative impacts on scientists' ability to engage in scientific inquiry and innovation. Trauma, stress, and anxiety can impair cognitive function and lead to decreased productivity and creativity. It has been shown that adverse life events, such as bereavements in the family, can lower productivity (e.g., Oswald et al. 2015). Finally, the direct loss of lives because of war action can deplete a country's scientific workforce.

The Effect of War-Induced Occupational Mobility on Scientific Human Capital

Furthermore, war may induce researchers to leave science to pursue other activities. Such occupational mobility may be caused by reductions in funding for research or by damages to physical infrastructure. After the collapse of the Soviet Union, for example, many researchers left the science sector because of low salaries and lack of materials and resources needed to do research (Ganguli, 2017).

However, wars and conflict can also provide opportunities for researchers to remain in science and to even accumulate further scientific human capital through targeted training programs and R&D investment. For example, a training program for medical school graduates in the United States during the Vietnam War, the National Institutes of Health "Yellow Berets" program, increased the likelihood that participants entered research-focused positions over purely clinical ones (Azoulay et al., 2021).

During WWII, the U.S. government made R&D investments via the Office of Scientific Research and Development (OSRD) by awarding contracts to firms and universities to conduct war-related research. The mandate of the OSRD's Committee on Medical Research was to mobilize medical researchers and pursue such contracts. These investments subsequently increased employment and entrepreneurship in high-tech clusters (Gross and Sampat, 2020; Gross and Sampat, 2022).

2.3 Lessons for Ukraine

Because of the large and often irreversible consequences of losing scientific human capital, the future of research in Ukrainian universities crucially depends on effective policies to preserve scientific human capital. As in other conflicts, the main threats to preserving scientific human capital are emigration, direct death and trauma caused by the war, and occupational mobility into sectors outside science.

Since the beginning of the war, there have been several initiatives to facilitate the emigration of Ukrainian academics. Many foreign universities have introduced fellowship programs for Ukrainian academics to travel abroad for short and long-term research stays (e.g., the University of Cambridge, the University of Munich, to name just a few). Similarly, scientific societies have started many initiatives to support research visits of Ukrainian scholars at foreign universities (e.g., Shevchenko Scientific Society, the British Academy, the Review of Economic Studies).

In addition, grassroots movements have sprung up to facilitate emigration. For example, *#ScienceForUkraine* an initiative that began on social media now hosts a central database listing opportunities abroad for Ukrainian academics. By June 2022, #ScienceForUkraine's database contained over 2,600 listings, with 16% of opportunities offered by German institutions, 9% by French and 7% by Polish institutions (Rose et al., 2022). These programs play an important role in safeguarding the livelihoods of Ukrainian academics. They are also a way of strengthening the scientific workforce of the host countries.[10]

Nevertheless, it will be important to supplement such programs with efforts to preserve the human capital of Ukrainian universities, especially after the war has ended. A possible way are grants and virtual/remote/non-resident fellowship programs that support scientists who remain in Ukraine. These types of fellowships that allow Ukrainians to remain in Ukraine while doing their research are already proliferating and are funded by universities and other organizations (e.g., Scholars at Risk (SAR), Universities for Ukraine (U4U), Duke University, University of Massachusetts).

After the war has ended, it will be important that Ukrainian scientists who have emigrated abroad return to Ukraine. In other war and conflict situations, return migration has been rather limited (e.g., Becker et al., 2021; Grüttner, 2022). Evidence from return migration in other contexts, however, points to potentially significant benefits to the home country in terms of knowledge spillovers and productivity gains (e.g., Bahar et al., 2022, Kahn and MacGarvie, 2016, Fry and Ganguli, 2023).[11] Fellowships and

[10] A number of papers have documented that high-skilled scientists can have large effects on science and innovation in the host countries (e.g., Hunt and Gauthier-Loiselle, 2010; Kerr and Lincoln, 2010; Moser et al., 2014; Moser and San, 2022).

[11] Yet cautionary evidence from an existing return migration fellowship program, China's Thousand Talents program, suggests that fellowships can help incentivize return migration of good - but not the

large research grants to do science in Ukraine could be effective tools to encourage such return migration.

To aid the reconstruction of the Ukrainian university sector, it will also be paramount to keep individuals in the scientific sector. Because of the war, there have been significant budget cuts for universities and research institutes in Ukraine. These cuts have already resulted in the termination of funding for existing projects and layoffs (Gorodnichenko et al., 2022). Such layoffs often lead to irreversible occupational re-orientations that have the potential to reduce Ukrainian scientific human capital in the long run.[12]

Previous research has shown that after the collapse of the Soviet Union small grants to close to 30,000 scientists funded by George Soros induced scientists to remain in science (Ganguli, 2017). During the current conflict, the Simons Foundation, for example, has funded grants to Ukrainian scientists, including salaries to 405 specialists and doctoral candidates to continue their research in Ukraine.[13] Such grants can be an effective and low-cost policy tool.

3 War and Physical Capital

3.1 Physical Destruction of Ukrainian Universities

The war in Ukraine has had a devastating impact on the country's scientific infrastructure. Because of the ongoing war, more and more universities have suffered from some physical destruction. As of March 2023, the Ukrainian Ministry of Education and Science reported that 3,145 educational institutions (such as schools and universities) had experienced physical destruction due to bombing and shelling.[14] For the same date, the ministry reported that 91 research and higher education institutes had been damaged, 4 had been destroyed, and 228 had had no damage (Irwin, 2023). This indicates that 29.4 percent of all research and higher education institutions had experienced at least some war-related destruction of physical capital.

highest-caliber - emigrants (Shi et al. 2023).

[12] However, there is also some evidence that the Ukrainian government is currently prioritizing war-related research. This could potentially keep researchers in the scientific sector if such efforts were sustained.

[13] https://www.nytimes.com/2023/01/25/science/ukraine-scientists-simons-foundation.html

[14] The Ukrainian Ministry of Education and Science provides oblast-level information on the number of schools, colleges and universities that have been damaged since the beginning of the war (https://saveschools.in.ua/en). These data, however, do not list specific universities that were damaged.

As the ministry's data do not list specific universities, which would allow us to link to damaged universities to publications, we turn to the sample of top 100 Ukrainian universities discussed earlier. To obtain estimates of physical destruction among the top 100 Ukrainian universities, we search for news articles and other information on English-language and Ukrainian-language websites. It is important to note that such articles usually do not report minimal damages. Hence, our measure of destruction measures relatively substantial damages. For example, the BBC reported that "a Karazin National University building in central Kharkiv caught fire after being hit by a missile".[15] Based on such information, we find that 22 of the top 100 universities have had some war-related damage (Table 1, Panel A). Many of the top 100 institutions are located in Kyiv, which experienced less war action than the areas in Eastern Ukraine. As a result, the share of damaged institutions is somewhat smaller for the top 100 universities than the overall share of 29.4% reported by the ministry. Moreover, the ministry's total includes research institutes as well as a larger group of universities, while ours includes only the top universities.

We note that estimates of the monetary value of damages are uncertain, but the National Academy of Sciences of Ukraine (NASU) estimated damages to research institutions of 0.5 billion hryvnia (approximately $13 million) as of October 2022 (Gorodnichenko et al., 2022).

Has the Destruction of Physical Capital Affected Ukrainian Scientific Production?

To gauge the short-run impact of physical destruction on scientific production, we compare trends in the number of papers in universities with and without war-related destruction. For this analysis, we collect data from *Clarivate Web of Science* which allow us to count the number of papers published by at least one author with an affiliation in a top 100 university. We then analyze whether universities with destruction of physical capital experienced a stronger decline in scientific production than universities without destruction.

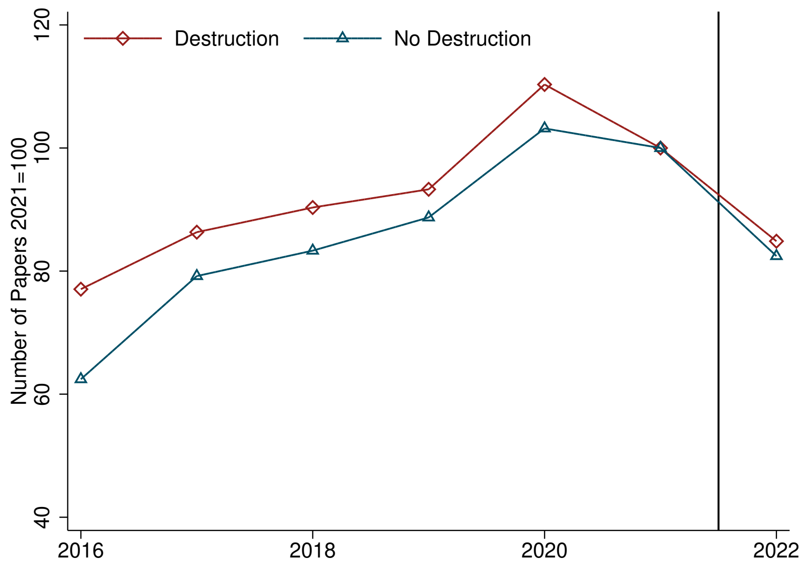
To ease comparison, we normalize the number of papers in each group to 100 for 2021, the last year before the war.[16] Between 2021 and 2022 the total number

[15] https://www.bbc.com/news/av/world-europe-60585633.

[16] In the appendix we report the equivalent figure without normalization (Figure A.1).

of papers declined in both groups of universities (Figure 2). However, there was no disproportionate decline in universities that experienced physical destruction.

Figure 2: Number of Publications by Destruction of Physical Capital



Notes: The figure shows the total number of papers by Ukrainian scientists top 100 universities in the *Web of Science*. To ease the comparison, we normalize the number of papers in each group to 100 for 2021. The red line shows the number of papers by scientists in top 100 universities that experienced destruction of physical capital. The blue line shows the number of papers in top 100 universities that did not experience destruction of physical capital.

While these results suggest that physical destruction only had a limited impact on scientific production to date, it is important to note that there are significant publication lags in publishing research. As a result, the destruction of physical capital may not yet have visibly affected publication outcomes in 2022.

Nevertheless, these results suggest that the sharp decline in Ukrainian scientific output between 2021 and 2022 was not predominately driven by the destruction of research laboratories and other physical capital. Rather it suggests that shocks to scientific human capital are the main source of the decline so far. This is quite consistent from the existing evidence on effects of physical capital destruction during WWII, which we describe next, that suggests that shocks to physical capital can be remedied more easily than shocks to human capital.

3.2 The Effect of War and Conflict on Physical Capital

Only a few papers have studied how destruction of physical capital affects scientific output. The physical capital destruction of WWII reduced output of German and Austrian universities by about five percent in 1950. By 1961, most of the effects of physical capital destruction had dissipated, and universities that had been destroyed during WWII produced as much output as those that were not destroyed (Waldinger, 2016). By 1970, universities that had been bombed even fared somewhat better than those that had not been affected, suggesting that bombed departments benefited from upgrading during postwar reconstruction. The evidence on the short and long-run effects of physical capital destruction during WWII suggests that shocks to physical capital can be remedied more easily than shocks to human capital.

While the loss of general physical capital can be overcome relatively quickly, recent research indicates that the loss of more specialized physical capital, e.g., equipment or material that has been developed by individual scientists for their specific research purposes, such as novel instruments or genetically engineered animals, is harder to overcome (Baruffaldi and Gaessler, 2021). Baruffaldi and Gaessler (2021) show their effects on general and specific human capital by studying a range of adverse events such as explosions, fires, or floods. This research also confirms that the replacement of obsolete physical capital can have positive effects on scientific productivity.

3.3 Lessons for Ukraine

The destruction of physical capital can affect scientific production, especially if destruction is at a larger scale, such as the WWII destruction in Germany and Austria. While the western parts of Ukraine have not experienced large-scale physical destruction, many cities and universities in the East have been heavily destroyed.

Rebuilding such physical infrastructure will be important to aid with the reconstruction of Ukrainian universities and research institutions after the war. It is also important to keep in mind that Ukraine's research infrastructure was already outdated and had little investment in recent decades (Gorodnichenko et al., 2022). This suggests that the investments made during the reconstruction will need to be even higher. However, the research on the destruction of physical capital also suggests that upgrading during reconstruction may have positive effects. This may even be beneficial for Ukrainian universities in the future. As discussed earlier, efforts to rebuild destroyed institutions must critically be complemented by funding for the scientists who work there.

4 War and International Scientific Cooperation

In addition to the loss of human and physical capital described earlier, the war has also hindered the exchange of scientific knowledge and ideas. Travel restrictions and the general insecurity in the country have made it more difficult for Ukrainian researchers to attend conferences, seminars, and travel to work with coauthors.

Several international conferences that were scheduled to be held in Russia were cancelled or were rescheduled in other locations. For example, the International Math Congress (ICM) was scheduled to be held in St. Petersburg in Russia in July 2022. In May 2022 it was announced that it would take place as a fully virtual event.[17]

Furthermore, interruptions of collaborations with Russian coauthors may have affected knowledge exchange between these two countries, which traditionally had strong scientific ties.

The consequences of such interruptions to international knowledge flows are twofold. First, science as a whole loses because scientists have worse access to knowledge that forms an input in their production of new knowledge. Second, such effects are more pronounced for scientists in countries that suffer disproportionately from the disruption of international knowledge flows (Iaria et al. 2018). In the current war it is likely that Ukrainian and Russian scientists are most affected.

4.1 The Effect of War on International Collaboration of Ukrainian Scientists

To study the short-run effects of the war on international scientific collaborations of Ukrainian scientists, we collect new data on international coauthorships from *Clarivate Web of Science*. The data contain all papers in the *Web of Science* that were published with at least one Ukrainian coauthor. For this analysis, we exclude papers without international coauthors. This enables us to compute the share of coauthoring with

[17] https://www.mathunion.org/icm/virtual-icm-2022 Already on February 24, 2022, American Mathematical Society (AMS) President Ruth Charney in a statement said that " The AMS has no plans to send representatives to a meeting in St. Petersburg" and urged "the International Mathematical Union not to hold the ICM in Russia in July 2022." https://insidehpc.com/2022/02/american-mathematical-society-cancels-participation-in-2022-icm-conference-in-russia/

authors from various countries among all internationally coauthored papers. We then calculate changes in coauthoring of Ukrainian authors with international coauthors between 2021 and 2022.

Coauthoring of Ukrainian authors with authors from Western Europe remained almost constant between 2021 and 2022 (see Figure 3). The share of coauthoring with authors from Eastern Europe increased by around 6 percent, while the share of coauthoring with authors in North America declined by about 6 percent. In sharp contrast, the share of coauthoring with coauthors in Russia declined sharply, by about 40 percent. This decline is even more dramatic if one considers that the Russian invasion did not commence until February 24, 2022, and that there are substantial publication lags in the sciences. The decline of coauthoring with authors from Belarus was similar to the decline with Russian authors.[18]

In the appendix, we show longer-run trends in international coauthoring by Ukrainian scientists (Figure A.2). Notably, the documented patterns are not an artefact of using data from *Clarivate Web of Science*. In fact, Van Noorden (2023) shows similar changes using publication data from Scopus.

4.2 The Effect of War and Conflict on International Knowledge Flows and Scientific Collaboration

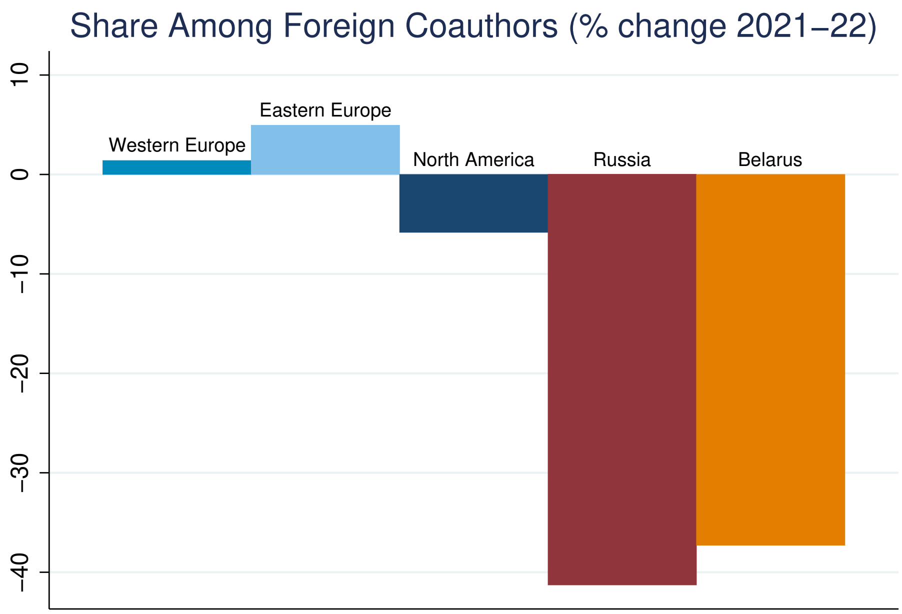
Prior literature has documented that wars can lead to severe disruptions of cross-border knowledge flows and international scientific collaborations. The Allied boycott against scientists from Central countries reduced international scientific collaborations during and after WWI (Iaria et al. 2018).[19] Scientists from Central countries were banned from attending international conferences, and the delivery of scientific journals to countries in the opposing block was severely delayed.[20] The decline in scientific collaborations

[18]It is important to note, however, that coauthoring with authors from Belarus is much rarer (see Figure A.2).

[19]During WWI the world split into the Allied (United Kingdom, France, later the United States, and a number of smaller countries) and Central camps (Germany, Austria-Hungary, Ottoman Empire, Bulgaria). The involvement of scientists in the development of chemical weapons and other war-related research and the extremely nationalistic stance taken by many scientists pitted scientists in the two camps against each other and led to severe disruptions of international scientific collaborations.

[20]The importance of international conferences for the exchange of knowledge has also been demonstrated by other research. The cancellation of a major political science conference due to a hurricane reduced the likelihood of collaboration with other attendees compared to attendees at similar conferences that did take place (Campos et al., 2018).

Figure 3: Share Among Foreign Coauthors (Percentage Change 2021-22)



Notes: The figure shows changes between 2021 and 2022 in coauthoring of Ukraine-based authors with coauthors from abroad. The figure is based on all papers in the *Clarivate Web of Science* with at least one coauthor from a Ukrainian university.

reduced the flow of scientific knowledge, as measured by citations to papers from the opposing block. As a result, scientists who were more dependent on foreign knowledge suffered severe reductions in their scientific productivity.

War and conflict have also disrupted international knowledge flows during other episodes. During the Cold War, there were significant barriers to scientific cooperation between the East and the West. Political tensions and ideological differences often made it difficult for researchers from opposite sides to collaborate or exchange information freely (e.g., Ganguli, 2015; Borjas and Doran, 2012). After the end of the Cold War, the subsequent immigration of Russian scientists to the United States increased citations by U.S. based researchers to Soviet-era work (Ganguli 2015). Similarly, book translations between the formerly opposing blocks increased dramatically after the fall of the Iron Curtain (Abramitzky and Sin, 2014).

War and conflict can also affect international knowledge flows by disrupting or breaking up international research teams. The loss of coauthors can have severe impacts on the research output of scientists (e.g., Borjas and Doran, 2015; Azoulay et al., 2010;

Jaravel et al., 2015; Poege et al., 2022).

4.3 Lessons for Ukraine

As shown above, the war has already disrupted scientific collaborations between Ukrainian and Russian scientists. Such disruptions can have long-lasting effects on scientific productivity, especially for those scientists whose research is more dependent on accessing international scientific knowledge.

Calls for boycotts have a long tradition in science.[21] However, the literature strongly suggests that such boycotts harm not only the boycotted scientists but also the boycotting ones (Iaria et al., 2018). As a result, boycotts slow down long-run scientific progress and are thus harmful for the scientific community as a whole. Furthermore, such boycotts harm the productivity of individual scientists whose research relies on the international knowledge that is cut off through the boycott. This would suggest that Ukrainian scientists themselves could suffer in such a boycott.

To mitigate the effect of reduced international scientific cooperation on Ukrainian science, programs to increase remote/virtual interactions with the international scientific community should be a priority. After the end of the war, questions will be raised regarding a potential return to scientific collaborations with Russian academics. Such a return to normal scientific collaboration will seem very far-fetched and maybe even inconceivable for many scientists in Ukraine. However, the historical evidence indicates that even after WWI with millions of deaths and very severe involvement of scientists in the war effort, the warring camps came together within a decade (e.g., Schroeder-Gudehus, 1973; Cock, 1983; Lehto, 1998; Iaria et al., 2018). Such reconciliation would benefit overall scientific progress.

5 Epilogue

In this article, we have shown that the war in Ukraine already affected science in Ukraine. These impacts will likely get worse if the war continues. Our data suggest that shocks to Ukrainian scientific human capital have already affected the output of Ukrainian universities, while shocks to physical capital have not yet visibly affected scientific production. Furthermore, international scientific collaborations with Russian scientists have declined dramatically since the war has started.

[21] See Blakemore et al. (2003) for a discussion on the justification of boycotts in science.

Based on these data and on our analysis of the economics of science and innovation literature, we argue that policies during the war and post-war reconstruction should prioritize the mitigation of shocks to human capital (and to scientists' access to international knowledge). Emigration and occupational re-orientation have long-run consequences, through network effects and through reduced training of young researchers. Such shocks, therefore, have the potential to leave scars that last for decades. It will thus be critical to support scientists who remain in the country and to incentivize return migration to Ukraine after the war has ended. Similarly, programs to keep researchers in the science sector while the war lasts can help alleviate shocks to human capital.

While calls to provide assistance for damaged facilities are important, such shocks to physical capital can be mitigated as long as sufficient funds for reconstruction are made available.

In this paper we have focused on how the war in Ukraine impacts science *in Ukraine*, but the war also has important implications for other countries and global science. While it is outside of the scope of this paper, we briefly highlight some of these impacts that policymakers should keep in mind.

First, for other countries, trying to attract Ukrainian or Russian scientists may still be a goal, and a large body of prior research shows how other countries can benefit from migration (e.g., Moser et al., 2014). However, from the perspective of reconstructing science in Ukraine in the long-run, these approaches should be pursued with caution.

Second, the impacts of the war on Russia and Russian academics are still unclear. Many Russian scientists and tech workers fled Russia after Western sanctions and due to the partial mobilization of men aged 18 to 60 across Russia to fight in Ukraine. European countries meanwhile have made it more costly for Russians to travel to the EU and temporarily suspended visa issuance and introduced restrictions around other immigration rules for Russian citizens.[22] Rather than the West, Russian scientists and tech workers appear to have gone to countries in the East, such as Turkey and Azerbaijan, but more data is needed to understand these flows. [23]

[22]https://www.consilium.europa.eu/en/press/press-releases/2022/09/09/council-adopts-full-suspension-of-visa-facilitation-with-russia/

[23]In the U.S., the Biden administration initially asked Congress to amend the Immigration and Nationality Act to allow Russians with an advanced degree in a science, engineering or math field to apply for a visa without first obtaining an employer sponsor in the US, but this was not pursued by the administration subsequently: https://www.cnn.com/2022/05/03/politics/visas-for-highly-educated-russian/index.html

To close, we stress that resources and expertise devoted to data collection to measure the effects of the war in terms of human and physical shocks will be needed to fully understand the effects of the war and to design effective mitigation and reconstruction efforts.

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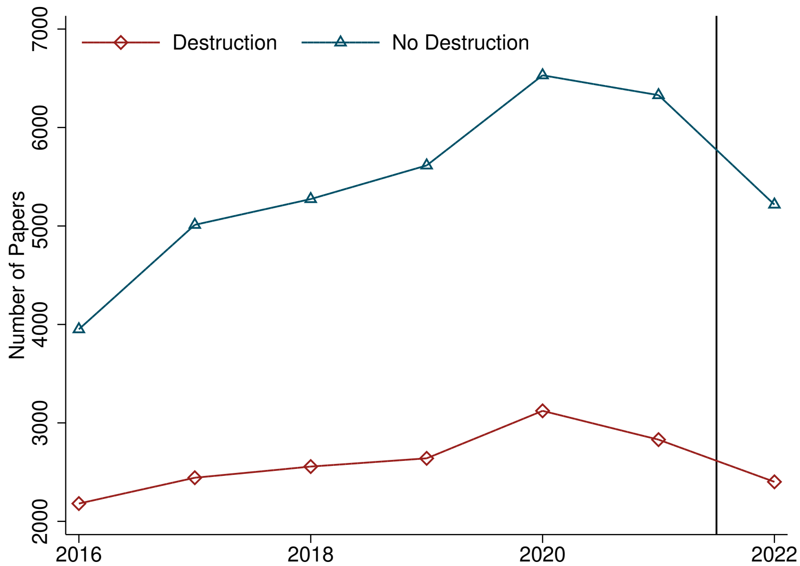
Appendix

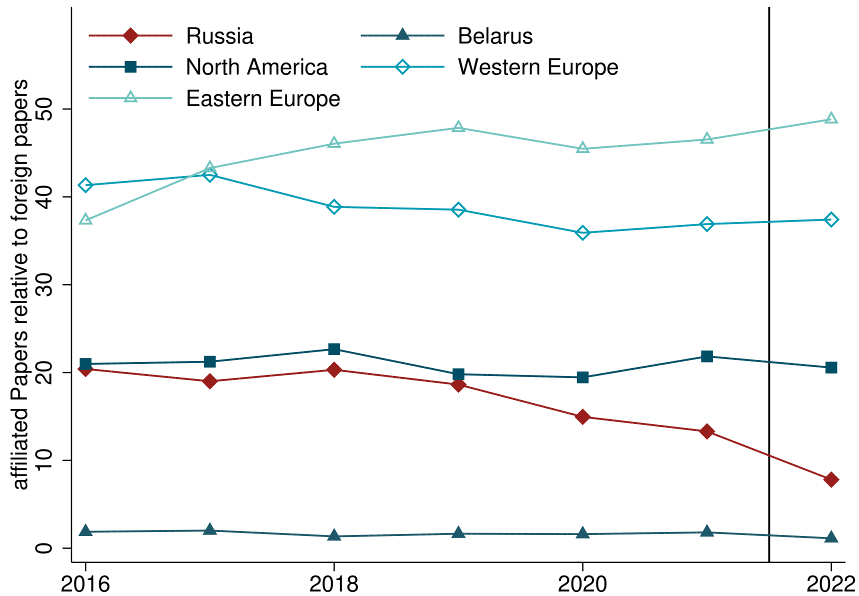
Figure A.1: Number of Publications by Destruction of Physical Capital - Absolute Levels



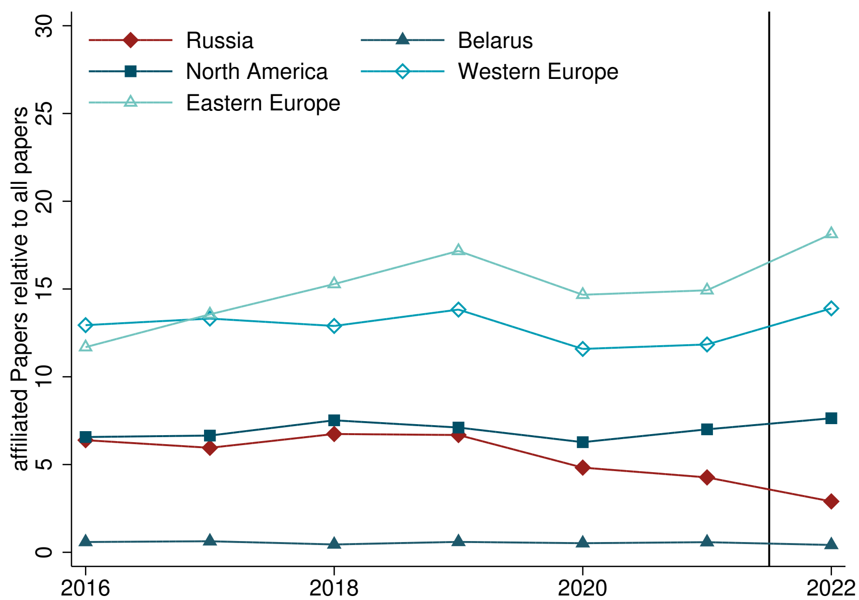
Notes: The figure shows the total number of papers by Ukrainian scientists top 100 universities in the *Web of Science*. It is the equivalent of Figure 2 without normalizing the total number of papers to 100 for the year 2021. As there are more universities without destruction the total number of papers is higher in that group. The red line shows the number of papers by scientists in the top 100 universities that experienced destruction of physical capital. The blue line shows the number of papers in the top 100 universities that did not experience destruction of physical capital

Figure A.2: Share Among Foreign Coauthors

(a) Share Among All Internationally Coauthored Papers



(b) Share Among All Papers



Notes: The figure shows the share of papers coauthored with authors from various regions/countries from 2016 to 2022. Panel (a) reports The figure is based on all papers in the *Clarivate Web of Science* with at least one coauthor from a Ukrainian university.