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Abstract: The ongoing war in Ukraine has unsettled the Ukrainian scientific community in ways that have not been quantified. Some scientists have left the country or changed jobs. For those who remain in research, the destruction of civil infrastructure and psychological stress may dramatically slow down research progress. Based on a survey of over 2,500 Ukrainian scientists, we estimate that by the Fall of 2022, around 18.5 percent of the population of Ukrainian scientists fled the country, and around 17.6 percent left academia or stopped conducting research. Considering reductions in research time, we estimate that Ukraine has lost a fifth of its research capacity and, should the war stop today, about seven percent of its scientists. We further utilize the survey to shed more light on scientists who left the country and those who remained in Ukraine and conclude by discussing potential policy measures.

Introduction

Russia's full-scale invasion of Ukraine on February 24, 2022, has killed many civilians, caused massive displacements of the population, and destroyed infrastructure to a significant extent. According to the Ministry of Defense of Ukraine, Russia fired half its stockpile of missiles in the first nine months of the war, resulting in severe civilian casualties.[1] Furthermore, in early 2023, about 18 percent of the population, or eight million people, have taken shelter in Europe, and a sizable share of the population has relocated to safer regions in Ukraine.[2]

The full-scale war (the 'war' in the remainder of the paper) is disrupting many sectors of activity. The Ukrainian science sector is no exception, with universities' closure—or destruction—and the career change, temporary or permanent, and escape of Ukrainian scientists (Stone, 2022a). History is rich with accounts of the mass fleeing of scientists, and economists have sought to quantify the impact these events had on innovation in the host countries (Borjas & Doran, 2012, 2015; Moser et al., 2014; Ganguli, 2015). The skills and tacit knowledge brought by migrants are generally seen as beneficial to the host countries (e.g., Saxenian, 2000; Franzoni et al., 2014), feeding the narrative of immigrant-friendly policies. Some observers of the current situation have called for hosting programs for refugee scientists and other active support measures for scientists staying in Ukraine (Duszyński et al., 2022; Kondratov et al., 2022; Maryl et al., 2022; Chhugani et al., 2022). Others have discussed how the war has affected collaborative research programs involving Russia (Stone, 2022b; Witze, 2022; Wojcik et al., 2022), noting a tendency towards reduced collaboration. The European Commission predicts that Russia "is likely to be severely hit" by the discontinuation of scientific partnerships with the EU and other countries (Ravet et al., 2022).

In the present paper, we seek to quantify critical parameters reflecting the extent to which the war has hit the Ukrainian scientific community. These include the extent of the 'brain drain' and other measures related to the research time and conditions of Ukrainian scientists, who either stayed in Ukraine or migrated to safer places. We report the results of a representative online survey of 2,559 scientists conducted between September 21 and December 8, 2022. The target population includes research-active employees of higher education institutions (HEIs) and public research organizations (PROs) who worked in Ukraine when the war struck.

Related Literature

The scientific human capital of countries is an essential factor for long-run competitiveness and growth. However, human capital is mobile, and extreme events, such as wars, economic downturns, and natural disasters, often prompt talented individuals to relocate to places offering greater safety and more attractive conditions. If sustained, this trend can have lasting effects on the home country (*e.g.*, Gibson & McKenzie, 2011), a phenomenon known as the 'brain drain' in the literature (*e.g.*, Docqier & Rapoport, 2012).

An important dimension of such brain drain that received much attention from prior research is the emigration of scientists (*e.g.*, Ganguli, 2014). Especially in times of war, leaving the country might be an appealing option for residents of that country, including scientists. However, not everyone has equal opportunities to emigrate, with more gifted individuals having more options

[1] "How many missiles Russia has left: commentary of the Minister of Defense of Ukraine," https://visitukraine.today/blog/1212/how-many-missiles-russia-has-left-commentary-of-the-minister-of-defense-of-ukraine, November 23, 2022. Last accessed October 17, 2023.

[2] UNHCR's Operational Data Portal (ODP), available at https://data.unhcr.org/en/situations/ukraine. Last accessed January 29, 2023.

than others (Ganguli, 2015b). Thus, it is likely that in times of disruption and war, countries lose their most productive scientists at a higher rate.

There is ample evidence suggesting that emigrant scientists can benefit professionally from migration. Such instances can facilitate learning and access to new knowledge and resources and have been associated with higher productivity after moving (Franzoni et al., 2014; Pellegrino et al., 2023). However, the extent to which such positive effects can unfold ultimately hinges upon the environments and opportunities migrant scientists face (Kahn & MacGarvie, 2016; Gaulé, 2014). In the context of refugee scientists, it is conceivable that emigrating scientists are willing to accept sub-optimal conditions outside academia or in research environments that do not fully suit their expertise. Further, given the temporary nature of such arrangements, not all scientists might be integrated into the local research environment.

The net effect of the emigration of scientists on home countries is similarly ambiguous. On the one hand, emigration hurts the departed country. Losing its most productive scientists is not only a loss in itself for the country, but it may also harm the productivity of local collaborators (Azoulay et al., 2010; Jaravel et al., 2018) and the training and mentoring of future generations of scientists (Ganguli, 2014). On the other hand, the literature has identified some positive effects. First, internationally mobile scientists can act as 'bridges,' contributing to the creation of international networks and giving scientists in their home countries access to knowledge, resources, and collaborators (Fry, 2020; Agrawal et al., 2011; Scellato et al., 2017; Kerr, 2008). Furthermore, if emigration remains temporary, returning scientists can contribute to the diffusion of knowledge, know-how, and scientific practices, which can also benefit local scientists in their home countries (Jonkers & Cruz-Castro, 2012; Scellato et al., 2014; Saxenian, 2000; Wang, 2015). Thus, a country's ability to benefit from the emigration of scientists depends on whether those scientists maintain ties to local scientists or eventually return.

Given high-skilled emigration's profound policy implications, the topic has received a great deal of attention from prior research. However, we know comparatively little about how stayers fare in times of war. Scientists remaining in their home countries are affected by war in a multitude of ways that have been poorly documented. In an extreme context such as war, the physical and psychological burden for those who remain might be particularly brutal. A number of studies focus on how workers, such as soldiers and doctors, suffer from being deployed in war zones (De Rond & Lok, 2016; Hällgren et al., 2018). This evidence points to the fact that exposure to, or direct involvement in, the war causes stress and trauma and might make it impossible to conduct research.

There might also be additional effects on stayers. The destruction of infrastructure and resources might prevent scientists from accessing their lab or necessary materials, severely impeding scientific progress. Power outages and air raid alerts might also disrupt research. Furthermore, scientists might direct their attention away from research to deal with the consequences of the war. This could entail, for instance, internal migration to safer regions, increased responsibility to take care of family members, a greater focus on other income-generating activities, such as activities outside of academia, or a patriotic call to help the country in other ways, including enrolling in civil services or the military.

The Ukrainian Scientific Context

In Ukraine, as in many other former states of the Soviet Union, research and higher education were organized in separate institutions. Traditionally, basic research was conducted exclusively at the National Academies of Sciences, and universities did not conduct any research but solely focused on education (Balasz et al., 1995). With the post-soviet transformation and greater need for

international recognition, incentives and pressures for university scientists to conduct research have increased (*e.g.*, Shaw et al., 2013). Despite these changes, teaching remains the main activity, and the remuneration of academics is primarily based on their teaching load (Shaw et al., 2013). Further, the National Academies of Sciences remain essential for basic research (Balasz et al., 1995). Scientists can achieve different levels of post-graduate education, starting with a candidate of sciences degree (equivalent to a Ph.D.) and a doctor of sciences (Sc.D.) being the highest degree. Determining the precise number of research-active scientists is a challenging task. Reported numbers vary between 41,000 full-time equivalents in 2018 and 110,000 researchers in 2020 (State Statistics Service of Ukraine, 2020).[3]

According to information provided by the Ukrainian Ministry of Education and Science, as of July 2023, 74 out of roughly 300 universities were damaged or destroyed. About 51 percent of these are in the Eastern regions, and an additional 27 percent are in the South.[4]

Since the beginning of the war, international support for Ukrainian scientists has been large and covered both movers and stayers. On the one hand, foreign governments, institutions, universities, and individual scientists offered Ukrainian scientists hosting arrangements (including, *e.g.*, research grants and visiting positions), and initiatives to facilitate the discovery of such opportunities popped up, such as Science4Ukraine and through the ERA4Ukraine platform. On the other hand, initiatives to support scientists remaining in Ukraine have been proposed (Chhugani et al., 2022), for instance, through mentoring programs (*e.g.*, the EURAXESS virtual mentoring program 'Shape the future of a Researcher coming to Europe') or collaborative research grants.[5,6] In our view, however, although we cannot conclusively assert it, the bulk of the initiatives concern migrants, with support for stayers being less frequent or at least not as visible as for migrants.

Prior studies assessing the effects of war on Ukrainian scientists

Assessing the extent to which the war affects Ukrainian scientists and their research efforts is not trivial. A number of surveys have been conducted for various purposes and targeting various sub-populations. For instance, the initiative UAScience.Reload conducted several surveys on Ukrainian scientists. In spring 2022, they received 2,173 responses and found that around 14.7 percent of scientists were outside Ukraine.[7] For their second wave, conducted in fall 2022, they report a similar number of 12 percent (out of 1,729 total respondents).[8] In another survey, Maryl et al. (2022) aim to understand better the situation of Ukrainian scientists abroad. They collected 619 responses and reported that most scientists maintained their activities at their Ukrainian home institution, often with no or reduced salaries. They further find that over half of scientists abroad are affiliated with a foreign institution, mainly through temporary arrangements. Based on a bibliographic analysis of scientists with a pre-war Ukrainian affiliation, Ganguli and Waldinger (2023) find that around five percent of the most prolific scientists have started publishing with a

[3] https://www.oecd.org/ukraine-hub/policy-responses/the-future-of-science-in-ukraine-afbd05df/. Last accessed October 17, 2023.
[4] https://saveschools.in.ua, July 2023. Last accessed October 17, 2023.
[5] https://mentoring.euraxess.bg. Last accessed October 17, 2023.
[6] https://nrfu.org.ua/en/news-en/the-nrfu-and-the-snsf-will-launch-a-joint-call-in-2023/. Last accessed October 17, 2023.
[7] https://www.uascience-reload.org/2022/07/05/ukrainian-researchers-in-times-of-war-results-of-survey/. Last accessed October 17, 2023.
[8] https://www.uascience-reload.org/2023/07/06/key-results-of-the-survey-on-the-needs-of-ukrainian-scientists-second-wave-report/. Last accessed October 17, 2023.

foreign affiliation and that the number of papers published by Ukrainian scientists has decreased by about ten percent compared to the pre-war level.

Survey Design

To address the research questions, we conducted a survey that we distributed in four distinct waves from September 21 to December 8, 2022. The survey follows the same structure in all waves. It starts with asking for the respondent's consent and proceeds with two filtering questions, ensuring the participants belong to the target population. Of the 3,231 initial respondents, 413 were not employed by a Ukrainian HEI or PRO at the start of the war. Another 259 respondents spent less than three hours per week on research activities on average over the last three years before the start of the war. The Supplementary Material presents the survey flow and the detailed list of questions.

Wave 1 forms the bulk of the final sample. It targets a random selection of 6,996 scientists affiliated with a Ukrainian scientific institution who published at least one paper listed in the Web of Science or Scopus databases between 2011 and 2021. Following prior studies (*e.g.*, Franzoni et al. 2012), we collected contact details for survey participants from publicly-disclosed email addresses listed in scientific publications. We obtained 1,188 answers (before filtering), leading to an adjusted response rate of 19.3 percent (829 undeliverable emails). This figure is on the low end of other online surveys of scientists (Crespi et al., 2011; Franzoni et al., 2012; Baruffladi et al., 2012; Sauermann & Roach, 2014), probably owing to the challenging situations survey participants face. We have been able to infer the gender, region, and prolificacy of most sampled scientists, allowing us to perform a non-response analysis (see Supplementary Material).

Wave 2 reaches Ukrainian scientists through their universities. We sent an email to the corporate email addresses of all universities in the country using a list provided by the Ministry of Education and Science of Ukraine. We also selected the top 100 universities and manually searched for contact details of their faculties/schools, institutes, departments, and chairs.[9] Wave 3 reaches scientists through social media platforms (Facebook Messenger, LinkedIn, Telegram, Viber, and WhatsApp) and communication by the National Research Foundation of Ukraine. Finally, we disseminated Wave 4 through a mailing to Ukrainian email addresses gathered by a collective of Ukrainian scientists from scientific publications.

In contrast to Wave 1, Waves 2–4 were also allowed to be distributed through referrals. We encouraged target participants to forward the survey invitation to colleagues so that the response rate is irrelevant for these Waves. Besides, given the ad-hoc sampling in these Waves and the lack of information on non-respondents, we have no sound basis to perform non-response analyses. Table S1 and the Supplementary Material present additional information on the data sources for each wave. Figure S1 depicts the number of responses received each week for each wave, and Table S2 summarizes the main characteristics of respondents by wave. As can be seen, the majority of the responses were collected in a narrow time window of five weeks.

Representativeness of the survey

The four waves reach the target population through different networks and channels. A sampling strategy of this sort ensures a broad coverage of the population of interest in such a difficult situation. However, it calls for sampling adjustments to match the population's key characteristics.

[9] The list of top 100 universities is available at https://osvita.ua/vnz/rating/82821/. Last accessed October 17, 2023.

Sampling weights

We assess how our final sample's characteristics compare with the population of Ukrainian scientists. As shown in Table S2, we slightly oversampled Female scientists, who represent 55 percent of the population of Ukrainian scientists but 62.1 percent of the sample. It further becomes evident that we under-sampled the extreme age groups, *i.e.*, scientists below 30 and above 64 years old, but oversampled scientists between 30 and 59 years old. These age differences are likely a consequence of the sampling strategy, which targeted publishing and research-active scientists—hence, it is not clear that they represent a 'bias' in the statistical sense. Furthermore, we under-sampled Associate professors but oversampled Professors and Senior Researchers. The categories available in the survey were finer-grained than those we found in official statistics. We allocated our categories to those in the public statistics following the rules set out in Table S4.

To assess the distribution of respondents across regions, we assign the home region of respondents based on the name of the home affiliation they voluntarily provided to us. As most affiliation names were in Ukrainian, and many were abbreviated, we manually assigned the official institution name as provided by official sources, which also contains the Oblast in which the institution is located.[10] Figure S4 suggests that researchers from the center, particularly the capital city, are disproportionately represented in our sample. The map in Figure S5 shows the distribution of respondents across regions. Although we collected responses from all Ukrainian regions (except Crimea and Sevastopol), we note that responses spread unevenly. Around 50 percent of respondents come from Kyiv City and the regions of Kharkiv and Lviv. Only a few, and somewhat fewer than expected, come from the Kirovohrad, Luhansk, and Chernihiv regions.

Finally, social scientists are over-represented among our respondents, whereas Physical scientists are under-represented. The main reference numbers for the population used in Table S2 are those extracted from publishing authors between 2019–2021 based on the subject codes assigned to their publications. We fractionally allocate the 71,204 unique authors, defined by the author ID assigned by Scopus, to the scientific fields they pertain to.[11]

The above analyses reveal systematic differences between the sample at hand and the population along several characteristics. Further biases might arise from attrition, multiple responses, and non-responses (see supplementary material 'Assessing Representativeness' for a detailed discussion). Should these characteristics correlate with the extent to which individuals are affected by the war, sampling adjustments are required to derive population-level estimates from our sample. To alleviate this concern, we compute post-stratification weights following the method in DeBell & Krosnick (2009), as implemented in the R package 'anesrake.' This package implements an iterative process to match the proportions in the sample to the proportions in the target population for multiple characteristics. As the size and composition of sub-samples vary, depending on the variable of interest, we recompute the weights for each analysis. We do not compute sampling weights for the specific analyses on the sub-samples of stayers and emigrants since the population of interest is no longer the full population of Ukrainian scientists. To illustrate attrition, we include missing responses as an additional category.

[10] Available at https://registry.edbo.gov.ua/opendata/universities/?ut=1. Last accessed October 17, 2023.

[11] For instance, an author with four publications classified in Physical Sciences and one publication classified in Life Sciences will be classified as 80 percent Physical Sciences and 20 percent Life Sciences. Scientific fields are defined as the highest-level classification of the ASJC subject fields that Scopus assigns to each journal (we manually adjusted the most apparent lumping and splitting errors on the complete list of authors).

The validity of our statistical approach rests on two main assumptions. The sampling weights only account for bias if 1) they include all relevant observable characteristics (*i.e.*, affecting response rate and correlated with the outcome of interest), and 2) there are no other omitted relevant unobservable characteristics (*e.g.*, scientists in distress or cities that were particularly hit by the war may be less likely to respond and also be more affected by the war). Given that the scientists most affected by the war are less likely to respond to the survey, our estimates on how the war affects individual scientists are likely to be conservative.

Survey Results

In what follows, we will first focus on the most relevant population-wide outcomes, namely emigration, together with changes in time dedicated to research and occupational mobility. We will then zoom in on two distinct sub-populations, emigrants and stayers, and assess how the war affects them.

Population-wide effects

We first assess scientists' emigration rate from Ukraine and whether certain groups of scientists were systematically more likely to emigrate. We estimate that 18.5 percent of scientists have left the country since the start of the war (Panel A of Fig. 1). This 18.5-percent figure is surprisingly close to that estimated by the UNHCR for the whole Ukrainian population at the time of the survey.[12] It suggests that scientists are not more likely than the rest of the population to leave the country. Indeed, the mass migration of Ukrainians at all skill levels has already been observed by the UNHCR.[13] In normal times, the barriers to migration are purposefully more porous for high-skilled migrants. In times of war, however, these barriers are considerably lifted, allowing all socio-economic categories to migrate—at least those with financial means to flee the country. In that sense, similar emigration rates for scientists and Ukrainians as a whole are not necessarily surprising. However, this finding is interesting in its own right and does provide an external validation of our study design.

The multivariate regression results in Panel A of Fig. 1 investigate individual-level characteristics correlating with migration. They suggest that the most productive and research-active scientists left the country at a higher rate. In particular, scientists who spend more than 20 hours per week conducting research, scientists among the top ten percent most prolific, and scientists with the highest degrees (Ph.D. or Sc.D.) were significantly more likely to leave Ukraine compared to the other scientists (8%, 12%, and 11% higher, respectively). An F-test confirms that these indicators of research activity are jointly statistically significant ($F = 7.417$).

Female scientists' probability of leaving the country is also higher (5%, significant at the 10% probability threshold), with about 74 percent of the movers being female (not reported). In principle, men aged 18–60 are restricted from leaving the country, making it surprising to observe male migrant scientists. However, there were specific exemptions in place. For instance, male scientists were permitted to undertake brief journeys for conferences and research collaborations. Exceptions also extended to foreign students, individuals with disabilities, single fathers, and those who have three or more children.[14] The 74-percent figure is the combined effect of an overrepresentation of females among Ukrainian scientists and a greater likelihood of females

[12] https://data.unhcr.org/en/documents/details/96923. Last accessed October 17, 2023.
[13] https://data.unhcr.org/en/documents/details/99627. Last accessed October 17, 2023.
[14] There is also unauthorized migration, as reported, *e.g.*, in https://www.dw.com/en/how-ukrainian-men-try-to-get-around-the-ban-to-leave-the-country/a-62529639. Last accessed October 17, 2023.

leaving the country than men. We note that it is ten percentage points below the 85-percent figure reported by the UNHCR for the Ukrainian population.[15]

Another way the war affects Ukrainian research is that scientists spend less time conducting research or entirely leave academia. We estimate that 17.6 percent of surveyed scientists (migrants or not) are no longer in academia or research. Having left Ukraine significantly correlates with the probability of leaving academia or research (Panel B of Fig. 1). Scientists who left the country were 17 percent more likely to leave academia or research than non-migrants. Scientists from the South and East regions, close to the border with Russia, were also significantly more likely to leave academia or research than scientists from the other regions. However, they were not more likely to leave the country. This result can likely be explained by the fact that the war particularly affected these regions. We shed additional light on this issue in the section '*Situation of scientists remaining in Ukraine*.'

Turning now to the time that Ukrainian scientists spend on research, at home or abroad, we estimate that Ukraine has lost about 20 percent of its research capacity. The time the 'representative' scientist spends on research went from 13 hours before the war to about 10 hours since the war (Panel A of Fig. 2).[16] The contraction in research activity is not as severe as in economic activity. The Ukrainian Central Bank reported that the GDP fell by 29.1 percent in 2022.[17] However, the numbers are silent on the qualitative change that may have taken place. Some surveyed scientists noted that it is "psychologically difficult for everyone to work," implying that research hours may not be as productive as before the war. Other scientists, by contrast, reported "escaping into writing articles to abstract [oneself] from terrible realities." Furthermore, we cannot exclude the possibility that some scientists find themselves in better conditions to conduct research at home or abroad.

The situation of emigrant scientists

As just established, the most productive and research-active scientists left the country at a higher rate. It is, therefore, of particular interest to shed more light on their situation, their potential to further develop their scientific human and social capital, and their willingness to return. Many scholars account that temporary migration can be beneficial for home countries thanks to 'reverse spillovers' (*e.g.*, Docquier & Rapoport, 2012). For these spillovers to happen, however, emigrant scientists need to be in situations where they can develop their scientific capabilities and continue conducting academic research.

Over 75 percent of scientists actively engage with scientists at their host institution. At the time of the survey, close to 30 percent went as far as submitting a paper to a peer-reviewed journal or a conference proceeding (not reported). As shown in Panel A of Fig. S6, most scientists reported experiencing novelty in various forms, such as exposure to new ideas, tools, methods, and data. For example, 64 percent of scientists reported being exposed to new ideas to a large or very large

[15] UNHCR "Ukraine situation: Regional protection profiling and monitoring factsheet", December 2022. Available at https://data.unhcr.org/en/documents/details/97720. Last accessed October 17, 2023.
[16] These figures are obtained by taking the mid-point values of the time category and multiplying them with the proportion of scientists in that category. We have assumed a value of 30 hours for the category "More than 20 hours" and a value of 0 hour for the category "Up to 3 hours." Missing data were grouped with the category "Up to 3 hours."
[17] https://www.reuters.com/world/europe/ukraines-gdp-fell-291-2022-during-russias-invasion-2023-04-13/. Last accessed October 17, 2023.

extent. This result can partly be explained by the fact that 25–40 percent of scientists spend more than ten percent of their research time in an entirely new field (not reported).

We view exposure to novelty as an opportunity unless it reveals a skill mismatch. Such mismatches are a legitimate concern as hosting arrangements did not primarily prioritize research fit. To further probe this topic, we have asked scientists about the perceived effect of the stay abroad. An overwhelming majority of scientists (87%) believe their stay at the host institution will improve their scientific abilities, see Panel B of Fig. S6. This finding aligns with previous research that shows increased productivity for migrant scientists and inventors in other settings (Franzoni et al., 2014; Blinded). Should scientists return to Ukraine after the war, returnees may present an opportunity to lift the Ukrainian research.

Despite this favorable perception, most migrant scientists are under precarious contracts. About 58 percent of them are (or will be) affiliated with an HEI or PRO (Panel A of Fig. 3). Among those, 89 percent have secured a formal employment contract (29%), a paid visiting scientist position (15%) or a scholarship (45%) as reported in Panel B of Fig. 3. However, only a fraction of these contracts lasts more than one year (26%, not reported). Thus, at the time of the survey, a mere 14 percent of migrant scientists had secured a long-term contract in an academic host institution. This heterogeneity of arrangements and prevalence of short-term contracts align with the unpreparedness of many host countries and can be attributed to the uncertainty surrounding the duration of the war.

Furthermore, not all migrant scientists plan to return to Ukraine after the war, as Panel A of Fig. 4 suggests. We estimate that about 2.5 percent of the total mass of Ukrainian scientists may not return to Ukraine.[18] However, we do not find evidence that the willingness to return differs systematically between highly productive and less productive scientists (t-stat = -0.78, p-value = 0.44).

Additionally, migrant scientists declare to interact less with their fellow Ukrainian colleagues than before the war (Panel B of Fig. 4). This disconnection is strongest with scientists in Ukraine but is also visible with Ukrainian scientists in the host or other countries. The separation of the diaspora of Ukrainian scientists is likely to aggravate as the war lingers, making it more difficult to 'reconnect' after the war.

Situation of scientists remaining in Ukraine

We now turn to scientists who remained in Ukraine, the 'overlooked majority' of Ukrainian scientists. Some scientists reported staying in Ukraine to "help the armed forces." One scientist declared having enrolled in the army "as a genetic fingerprinting specialist." Another shared that he can use his "knowledge and professional skills [… to help his country…] more effectively […] outside of teaching and scientific work."

As the excerpts suggest, stayers may not be conducting research to the same extent as before. About 40 percent of stayers indicated to conduct less research than before the war. Note that this finding is likely an underestimation of the true value, as the survey only allowed the selection of categories of research time (*i.e.*, up to 3 hours, 3–5 hours, 5–10 hours, 10–20 hours, more than 20 hours), and changes within categories remain unobserved. Multivariate regressions (Ordered Logit Models, see Fig. 5) reveal some heterogeneity in changes in research time. They suggest that the most productive scientists and those working at the National Academies of Sciences were better

[18] We obtain the 2.5 percent figure by allocating the scientists who did not respond or do not know yet if they will return to Ukraine based on the proportions observed for those who know.

able to maintain their research time. In contrast, controlling for productivity, the more research-active scientists, *i.e.*, those who spent more than 20 hours per week doing research before the war, are more likely to report a significant decline in their research time.

A sizeable proportion of scientists in our sample indicated to have stopped conducting research altogether (10.1%) or reduced their research time to below three hours per week (18.6%), our threshold for defining non-research active scientists. Some scientists also indicated a more significant occupational change. A total of 15.3 percent of stayers indicated to have left academia altogether. The most research-active, as well as more senior researchers, were amongst the most likely to leave academia. However, one should interpret this finding cautiously, as respondents might have different perceptions of what 'leaving academia' means, particularly for those working at a public research institution (see Table S9).

Scientists who remain in Ukraine are much more likely to be exposed to life-threatening situations and challenged to find ways to mitigate these consequences. One way is to move to safer places within Ukraine. We estimate that 19.9 percent of stayers did so. Furthermore, note that, sometimes, research is not feasible even though resources have not been destroyed and access remains. Ukraine's power plants and electricity grid were the target of regular, massive shelling campaigns.[19] As one respondent explains, "Blackouts and bombing almost totally blocked the realization of the complex experimental protocols to study the nonlinear optical response of smart nanocomposites." A total of 23.5 percent of stayers report that they no longer have access to important inputs to their research. However, even though resources may be intact, 20.8 percent of stayers can no longer access their research institution in its original location. Of these, for 14.6 percent, access is only possible online, and for 4.2 percent, the institution itself has been relocated. A set of multivariate regressions reported in Table S9 suggests that scientists in the East and South regions were more likely to experience that situation but that there are otherwise no statistically significant differences across other demographic dimensions.

Concluding Remarks

The study highlights the effects of the war on Ukrainian research, based on a survey conducted between September 21 and December 8, 2022. We estimate that by the Fall of 2022, around 18.5 percent of the population of Ukrainian scientists fled the country. The findings further suggest that the most research-active Ukrainian scientists were among the most likely to leave the country. Measured in terms of time dedicated to research, we find that Ukraine has lost about a fifth of its research capacity. Besides these immediate effects, the current situation will also have long-term consequences. Science is fast-paced and competitive, and returning to scientific activities after the war may be challenging. Assuming that half of those who put aside their academic activities will not come back to science, our results suggest that Ukraine has already lost roughly seven percent of its scientists as a direct consequence of the war.[20] Furthermore, as the most research-active scientists leave the country, this brain drain will likely result in a 'lost generation' of Ph.D. students who will lack mentors and are already facing challenges due to interruptions caused by the war.

It is, however, important to note that this survey can only provide a snapshot of the complex situation faced by Ukrainian scientists, shaped by the context at the time of response. This caveat

[19] See https://www.osw.waw.pl/en/publikacje/osw-commentary/2023-01-18/verge-blackout-ukraine-facing-attacks-its-electricity. Last accessed October 17, 2023.

[20] We obtain the 7 percent figure as follows. Eleven percent of the 'drop-outs' among the 81.5 percent of scientists who remained in Ukraine, represents 9 percent of all Ukrainian scientists before the war. If half of them do not return to science, that's 4.5 percent. Adding the 2.5 percent Ukrainians who may not return lead to 7 percent.

is particularly relevant considering questions aimed at capturing intentions, for instance, the intention to return. Follow-up surveys are needed to provide more insights about the long-term effects of the war on science in Ukraine and shed more light on the situations of scientists at home and abroad. Furthermore, even though we go to great lengths to ensure the representativeness of the survey, responses should always be interpreted bearing potential non-response bias in mind. Finally, we have left many other important dimensions aside, not least the psychological effects of the war due to the constraints imposed by a survey research design.

A competitive science sector is an essential component of a modern nation. Foreign policymakers can help prevent further deterioration of Ukraine's science sector and plant the seeds of its renewal. Given the precarious conditions of migrant scientists, offering more and longer scholarships seems to be the number one priority for this group of scientists. Taking as a benchmark the contribution of the European Commission for a postdoctoral fellowship under the Marie Skłodowska-Curie Action (MSCA), we estimate that the funding need is in the ballpark of €700 million per year.[21] By hosting Ukrainian scientists, Europe allows them to keep abreast of scientific advances and provides them an opportunity to lift their research skills. Providing temporary academic shelter for Ukrainian scientists also helps them remain in the global scientific community, minimizing further losses to the Ukrainian science sector as the war continues.

However, such arrangements are unlikely to convert into long-term opportunities for migrant scientists. Obtaining positions in European scientific institutions was challenging enough before the war, and the influx of Ukrainian scientists puts pressure on an already underfunded and competitive system. Hence, it is unlikely that host countries' scientific institutions will offer enough long-term, stable prospects.

Although a significant focus has been put on migrant scientists, policy measures should not neglect scientists who remained in Ukraine. As a significant proportion of these scientists have lost access to their institutions and primary research inputs, measures should be considered to facilitate the continuation of research, such as remote visiting programs, access to online libraries and computing resources, or joint research grants. In light of the finding that migrant scientists seem to be slowly losing contact with their fellow Ukrainian colleagues, such programs also have the benefit of maintaining ties and fostering knowledge exchange between Ukrainian scientists.

Additionally, providing funding for encouraging returnees may also be beneficial when the war has ended. As our study shows, migrant scientists are being exposed to new knowledge and methods, which the country may need for its reconstruction. Furthermore, assuming that university funding will still be tied to teaching activities in post-war Ukraine, encouraging students to return to universities in Ukraine will also create more possibilities for Ukrainian scientists to return.

The war in Ukraine has caused disruptions in the scientific community, but with determined effort and concrete measures, we are hopeful that a brighter future for science can be achieved.

[21] The gross MSCA allowance is €5080 per month (depending on country) + €600 of mobility allowance + €660 family allowance, totaling €76,000 per year. This number of multiplied by the proportion of migrant scientists among the total number of scientists in Ukraine (18.5% of about 50,000).

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Figures

Fig. 1. Probability of leaving Ukraine and Academia. This figure shows the coefficients and the 90% and 95% confidence intervals of linear probability models predicting an individual's likelihood to leave Ukraine (**A**) or academia (**B**) based on a number of demographic characteristics.

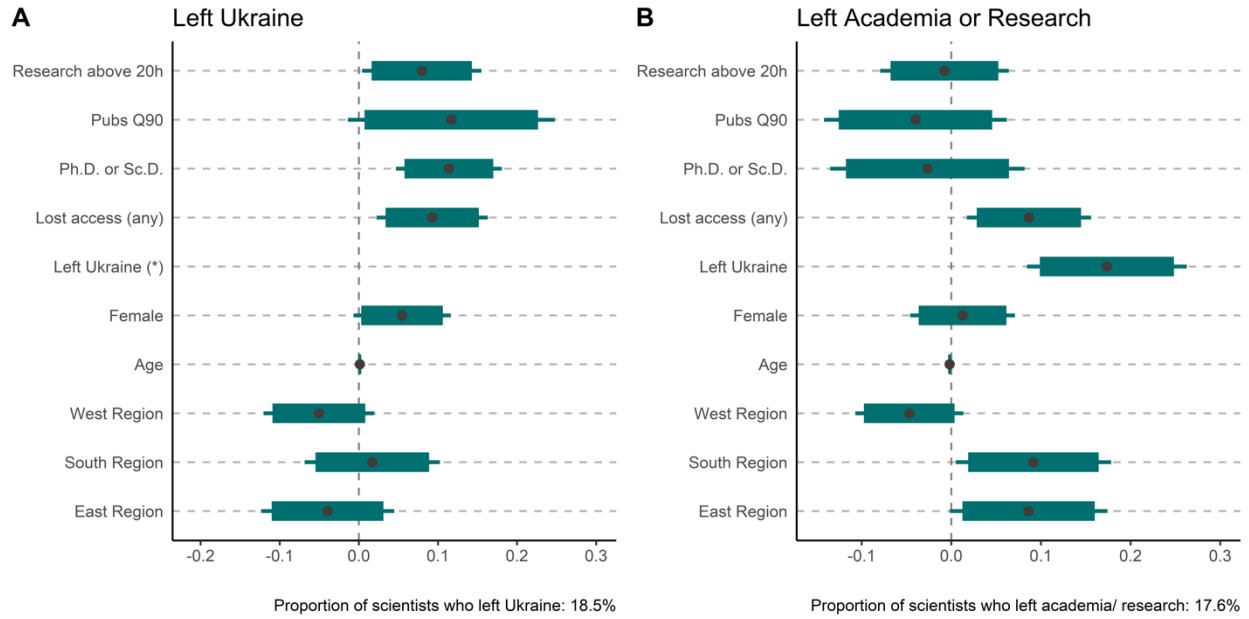

Fig. 2. Time allocated to research activities. Distribution of the number of hours per week allocated to research before and during the war (**A**)

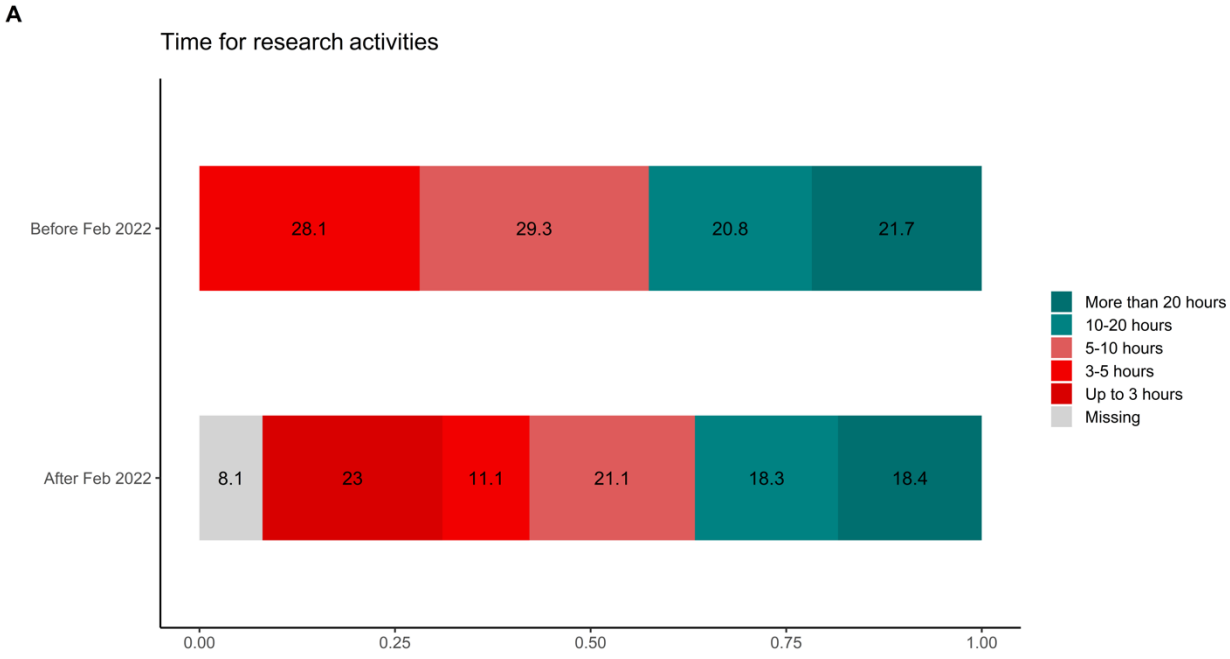

Fig. 3. Professional situation of migrant scientists. Type of institutions hosting migrant scientists (**A**) and type of agreement for migrant scientists hosted by an HEI or PRO (**B**).

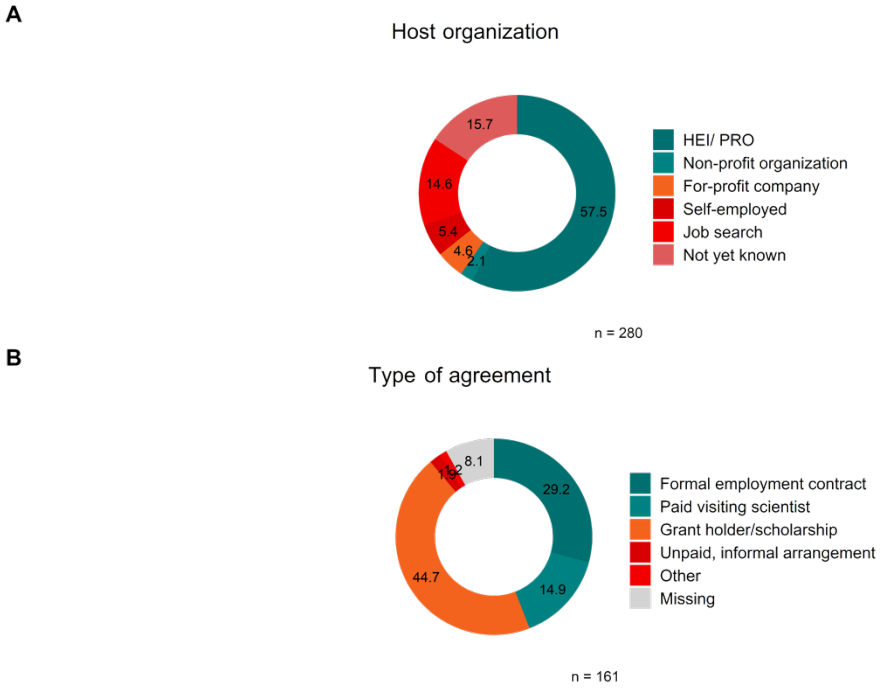

Fig. 4. Likelihood to return and Connection with community of Ukrainian scientists. Self-reported likelihood that migrant scientists return to Ukraine (**A**) and distribution of the changes in their interactions with various groups of Ukrainian scientists (**B**). 1.4 percent missing in Panel (**B**) third bar.

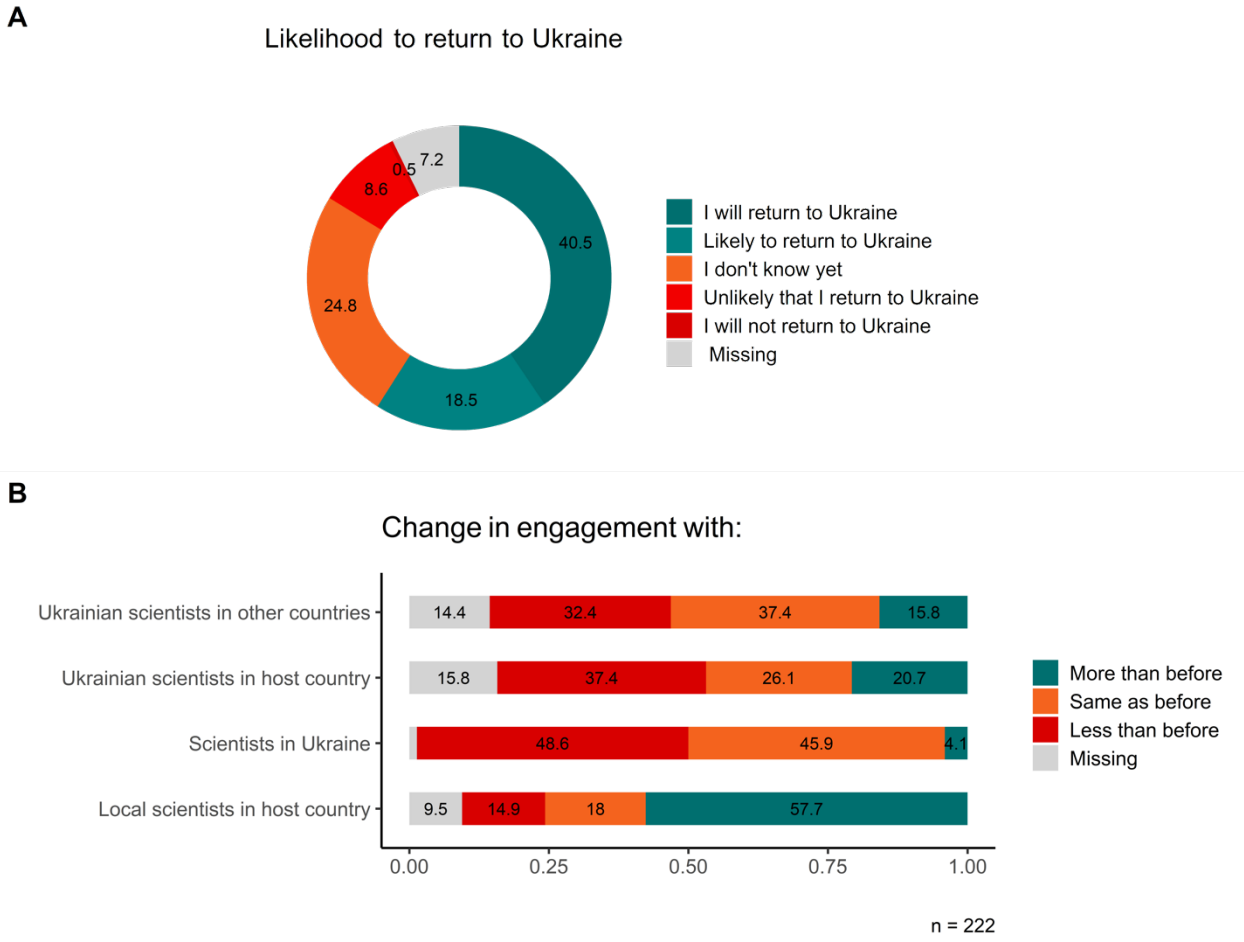

Fig. 5. Changes in research time for stayers. Results of ordered logit regression on the extent of reduction in research. No change and increase in research time were combined as the baseline category.

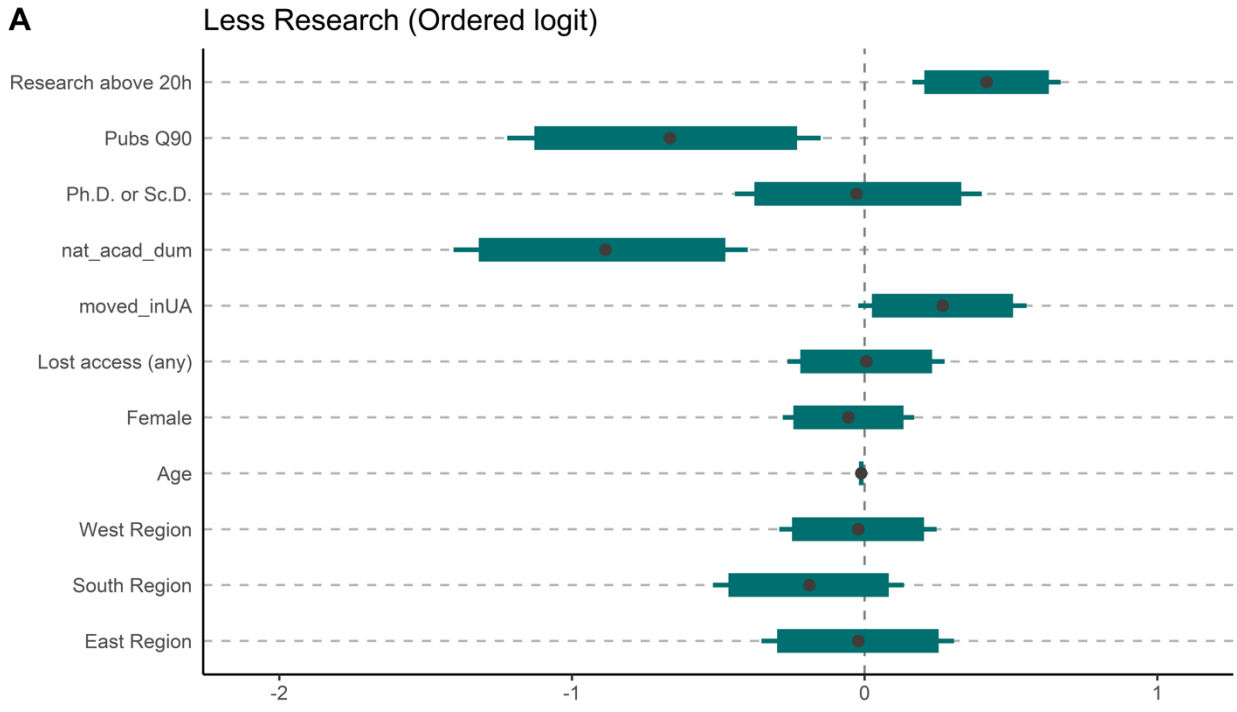

Fig. 6. Access to resources and Ukrainian institution of stayers. Type of access to Ukrainian institution (**A**) and type of access to research inputs (**B**).