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# Geo-political conflicts, sanctions, and international knowledge flows: EU-Russia collaboration during the Ukraine crisis

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**Abstract:** This paper studies the development of scientific co-publications between EU countries and Russia since the start of the Ukraine crisis in 2014. We investigate if economic sanctions and countersanctions imposed during the crisis affected EU-Russia knowledge flows even before all science collaborations between EU countries and Russia were eventually suspended as part of EU sanctions in 2022. Our econometric analysis uses a gravity model framework and a comprehensive dataset covering more than 540 million scientific publications and 8.6 million international co-publications for 35 countries (EU, BRICS, Belarus, and Ukraine) during 1995–2018. Findings indicate that the imposition of EU sanctions and Russian countersanctions from 2014 onward had a significantly negative effect on EU-Russia co-publication intensities. As a lower-bound estimate, we find that sanctions reduced the EU-Russia scientific co-publication intensity by 15% at the aggregate level. Effects are higher in specific scientific fields. We uncover transmission channels of this effect, e.g., related to dual use technologies and growing resentments, and assess the robustness of our estimates. Time-dynamic regressions show that the sanctions effect on scientific collaboration increases over time. This underlines the susceptibility of global knowledge flows to geo-political conflicts.

**Keywords:** knowledge flows; scientific co-publications; EU-Russia relationship; Ukraine crisis; economic sanctions; gravity model

**JEL codes:** C23, F51

## 1. Introduction

The spiralling escalation of the Ukraine crisis since 2014 has moved economic sanctions to the fore of the political agenda in countries that condemn the Russian military aggression against Ukraine as violation of international law and a fundamental breach of the Ukrainians' right to self-determination (Sjursen & Rosén, 2017). While economic sanctions are a long-established trade policy instrument with clearly defined goals as to politically isolate the sanctioned country and place hardship on its socio-economic development (Hovi et al., 2005; Carbaugh and Gosh, 2019), evidence-based assessments of their effects remain a challenge (Afesorgbor, 2019; Hufbauer & Jung, 2020; Felbermayr et al., 2021). This is due to the unique historical and geopolitical context of the underlying conflict, its dynamic development, and the specific nature of how sanctions are implemented and anticipated.

Here, we study the impact of economic sanctions on international knowledge flows between EU countries and Russia in the years following the start of the Ukraine crisis in 2014. We complement prior work that has provided evidence on i) a decline in EU-Russia bilateral trade flows (Giumelli, 2017; Crozet & Hinz, 2020; Doornich & Raspotnik, 2020; Gullstrand, 2020; Crozet et al., 2021), ii) a significant drop in foreign direct investments (FDI) to Russia (Liuhto et al., 2017) and iii) a reduction in cross-border mobility between Russia and its neighbours (Prokkola, 2019). While these analyses are concerned with economic outcomes that are directly linked to trade sanctions, the indirect role of sanctions on academia, knowledge production and international knowledge exchange has been overlooked so far (Bezuidenhout et al., 2019). We argue that a focus on scientific knowledge exchange, which is measured in this paper through international scientific co-publications, is well deserved given its importance to spur innovation and economic development (Peri, 2005; Chen et al., 2019) as well as in addressing global social and environmental challenges.

The Ukraine crisis of 2014 constituted a major geo-political event that triggered an ongoing period of sanctions and countersanctions between EU countries and Russia (Caldara & Iacoviello, 2022). From March 2014 onwards, the EU and other Western countries such as the USA have imposed

restrictive measures against the Russian Federation including travel bans, asset freezes as well as sanctions on international trade for dual use goods and financial flows (European Council, 2023a). Over time, these sanctions have been systematically extended, particularly after the Russian military invasion of Ukraine in February 2022. It is important to stress that we focus on the EU-Russia sanctions period before the Russian military invasion, after which all research and innovation (R&I) collaborations between the EU and Russian entities have been suspended as part of EU sanctions (European Commission, 2022). This suspension of R&I collaborations was an unprecedented case in the recent history of EU sanctions and there is little doubt that this systematic suspension has influenced scientific co-publications as the outcome of R&I collaborations (Plackett, 2022). What we are particularly interested to study here is, instead, how international knowledge flows are affected when R&I collaborations take place in a grey zone under sanctions. This is typically the case when economic sanctions do not explicitly rule out R&I collaborations but may affect them indirectly.

In the case of the Ukraine crisis between 2014 and 2022 several factors may have contributed to such indirect effects: funding access to EU framework programmes was more difficult to obtain for Russian researchers or was explicitly suspended if research projects involved technologies with potential military applications; access to technology associated with dual use goods and researcher mobility between the EU countries and Russia were limited in several cases; and, on a more general level, the crisis may have led to resentment and academic boycotts towards Russian scholars and vice versa.

To estimate the effects of economic sanctions on international knowledge flows running through these channels, we exploit the quasi-experimental nature of the sanctions episode following a sudden political crisis (Bělín & Hanousek, 2021; Miromanova, 2022). Estimations are carried out through static and dynamic difference-in-difference (DiD) regressions within a gravity model framework for bilateral knowledge flows between EU member states, Russia, and other BRICS (Brazil, India, China, South Africa) countries. For robustness checks, we extend the sample to include Belarus and Ukraine

as alternative comparison units. Besides investigating the overall effect of sanctions on the total volume of scientific co-publications, we also seek to identify which scientific fields have been the most affected. This shall help us to answer the specific research question of this paper: *Did sanctions and countersanctions imposed in 2014 between the EU and Russia led to a significant decline in EU-Russia scientific collaboration?*

## 2. Economic sanctions and knowledge flows: Impact channels

The potential impact of economic sanctions on scientific collaboration between conflict parties in general and, particularly, in the case of the Ukraine crisis have remained largely unexplored. EU and Russian officials have traditionally been supportive of the idea of close collaboration between scientists from the EU and Russia (Yegorov, 2009). As described by Plackett (2022), before the Ukraine crisis, Western countries were eagerly embracing Russian scientists as research partners. However, while the sanctions imposed in 2014 did not explicitly exclude Russia from participating in international research efforts (Schiermeier, 2018), the geo-political climate seems to have impaired scientific cooperation between the EU and Russia even before the Russian invasion of Ukraine in February 2022. Potential transmission channels for this development are reductions in

i) research projects involving ***dual use technologies*** that are affected by EU trade sanctions,
ii) ***collaborative research funding*** due to restricted access of Russia to EU framework programmes,
iii) ***academic mobility*** between the EU countries and Russia and reduced opportunities for Russian academics to work in international laboratories.

Additionally, this geo-political conflict may have led to

iv) ***resentment/boycotts*** by the international scientific community towards Russia and vice versa.

***Dual use technologies:*** While there are very few studies that investigate knowledge flows in dual use technology sectors, the rationale for knowledge sharing between military industries and the civilian sectors lies in the possibility of creating synergies for innovation and social benefits (Acosta et al.,

2020). However, for obvious reasons such dual use technologies with potential military applications have been directly targeted by EU trade sanctions towards Russia: bilateral trade of such goods has been restricted and the cooperation with the Russian military-industrial complex and their suppliers was banned in 2014 (European Council, 2023a). The restrictions to research cooperation with foreign partners naturally thwart the research practices of knowledge sharing with Russia in subject areas linked to dual use technologies (Krige, 2014). The dual use technologies channel is, hence, most closely related to the imposition of EU trade sanctions towards Russia.

***Collaborative research funding:*** Participation in collaborative research projects has been remarked to create multinational networks that will give rise to international knowledge flows (Di Cagno et al, 2016). Thus, a decreased access to networks created by research funding is likely to lead to a drop in knowledge flows between Russia and the EU. The most recent figures on Russian participation in Horizon 2020 so far show a significant decline in comparison to the seventh framework (FP7), which is partly explained by the funding rules of Horizon 2020 (whereby Russian participants were not automatically eligible for EU funding). The number of Russian organizations participating in EU funded research projects dropped from 571 during the FP7 period 2007–2013 to 213 during the Horizon 2020 (H2020) period 2014–2020 (Figure C4 in the online supplementary materials). According to the European Commission (2018), the drop was due to the sanctions against Russia and the concerns about cooperation in some technologically sensitive areas that led scientists to think that Russian partners in Horizon 2020 collaborative projects would not be welcome (even before 2022).

***Academic mobility:*** International researcher mobility is seen as one of the main channels of scientific collaborations and knowledge flows (Petersen, 2018). A drop in academic mobility can be expected to reflect negatively on EU-Russia knowledge flows. While academic mobility was not as such initially targeted via sanctions, there seems to be a significant overlap in the slowdown of EU-Russia academic mobility and the sanctions period after 2014. For example, academic mobility between Russian and Finnish institutes of higher education plummeted from the ca. 4600 mobility periods in

2013 to only 2400 mobility periods in 2018 (Figure C2 in the online supplementary materials). Data on international student mobility similarly shows that the number of inbound students to the EU from Russia has fallen behind the trend for the other BRICS countries, particularly after 2014 (Figure C3 in the online supplementary materials).

***Resentment and boycotts by the international scientific community:*** There are clear examples in world history of actions and policies that have led to resentment and boycotts by the international scientific community such as the academic isolation of Central powers during World War I (Iaria et al., 2018) and the Apartheid era in South Africa (Sooryamoorthy, 2010). More recent geo-political events, such as the Russian annexation of Crimea, have once again sparked the legacy of animosity (generated by the Cold War) towards Russia in western countries (Harmeling et al., 2015). The actions by the Russian Federation against Ukraine are, thus, likely to have led to a resentment by researchers, along with the general public, from the EU towards collaboration with Russian scientists and vice versa (see, for instance, Figure C1 in the online supplementary materials). This has likely hindered EU-Russia knowledge flows even before the contemporary boycott that started after Russia launched a full-scale war against Ukraine in 2022.

However, from the EU perspective, the resentment towards Russia is not equally felt across countries. Citizens of Scandinavian and the Benelux countries and Germany had the most negative views about Russia, while the population of many eastern European countries, such as Bulgaria, Romania, and Slovakia, as well as Cyprus considered Russia in a more positive view (Eurobarometer, 2016; 2018, see Table C1 in the online supplementary materials). Similarly, governments of EU countries had varying stances towards the sanctions imposed from 2014 onwards. The governments of countries, such as the Baltic countries and Poland, were strongly in favour of imposing sanctions, while others, such as Hungary and Italy, have been considered more friendly towards Russia (Shagina, 2017).

## 3. Empirical strategy

To estimate potential sanction effects on international scientific co-publications through these channels, we run treatment effect panel data regressions within a gravity model framework. The gravity models have a long tradition in the estimation of treatment effects associated with factors fostering or hampering international relations (e.g., Baier & Bergstrand, 2007; Slavov, 2007; Larch et al., 2022). Gravity models for the analysis of knowledge flows have, for instance, been proposed in Peri, (2005) and Picci (2010) and Keller & Yeaple (2013). Our baseline specification is

$$rCOPUB_{ijt} = \beta_0 \cdot \mathbf{X}_{\mathrm{ijt}}^{\beta_1'} \cdot DIST_{ij}^{\delta} \cdot SANC_{ijt}^{\gamma} \cdot e^{\theta_i d_i + \theta_j d_j + \lambda_t z_t} \cdot \varepsilon_{ijt}, \quad (1)$$

where *rCOPUB* is the international co-publication intensity for country pair *ij* at time *t* as outcome variable, which is regressed against time-varying controls characterising the attractiveness of a country pair for scientific collaborations ($\mathbf{X}_{\mathrm{ijt}}$).[1] *DIST* is a measure for geographical distance working as an impediment to international knowledge exchange in the logic of the gravity model and $SANC$ is our treatment variable that captures the period of economic sanctions for EU-Russia country pairs; $d_i$ and $d_j$ are a set of dummies for countries *i* and *j* that serve as a proxy for multilateral resistance terms (Fally, 2015) and capture latent country differences in political institutions, the national innovation system etc. Further, $z_t$ are dummies for individual sample years to cover time trends and shocks (e.g., business cycle movements) common to all country pairs; $\varepsilon_{ijt}$ is an *i.i.d.* error term; $\beta_0$, $\beta_1'$, $\delta$, $\gamma$, $\theta_i$, $\theta_j$ and $\lambda_t$ are parameters to be estimated.

As an extension to the basic gravity equation shown in equation (1), we estimate the gravity equation including country-pair dummies $\theta_{ij} d_{ij}$, which additionally capture structural differences between individual pairs of countries such as common language, historical and political ties. We also interact

[1] We construct control variables ($\mathbf{X}_{\mathrm{ijt}}$) as products of country pairs; for instance, $GDP_{ij}$ enters the gravity equation as $GDP_{ijt} = (GDP_{it} \cdot GDP_{jt})$, treating variables as pairwise (dyadic) measures (Rose, 2004). Similarly, we also include the product of scientific publications (*PUB*) for country *i* and *j* at time *t* in the set of control variables. Finally, we also include the bilateral international trade intensity among the set of control variables.

the included time trends with country dummies, i.e., $\Psi_{it}(d_i \cdot z_t), \Psi_{jt}(d_j \cdot z_t)$ for which the coefficients $\Psi_{it}$ and $\Psi_{jt}$ capture time-varying country heterogeneities in co-publication activities potentially confounding with the treatment effects of sanctions. We refer to this complex set of dummies as multidimensional fixed effects (MD-FE) structure.

The treatment variable $SANC$ is a binary dummy that takes a value of 1 for all country pairs that include Russia and any of the 28 EU countries from 2014 onwards; it is zero otherwise. This means that scientific collaboration within the EU, between EU countries and the remainder BRICS countries (excluding Russia) as well as within the group of BRICS countries (including Russia) serve as comparison units for the temporal evolution of EU-Russia scientific collaboration in the logic of difference-in-difference (DiD) estimation. If $\gamma$<0, EU-Russia scientific collaboration intensity falls short of those in the comparison group of non-treated country pairs after treatment start. We take this as evidence for a negative effect of economic sanctions on knowledge flows.

To test for early anticipation and/or gradual phasing-in effects, i.e., dynamically evolving treatment effects, we also estimate gravity model specifications with separate treatment indicators for individual sample years $\sum_{n=-N}^{N} SANC_{n,ijt}^{\gamma_n}$, where [-*N*,*N*] describes the maximum number of leads and lags relative to the imposition of the sanctions in 2014; each parameter $\gamma_n$ measures the effect for a lag/lead year. Following the discussion of DiD estimation with multiple time periods (Callaway & Sant'Anna, 2021), our flexible DiD regression specification with MD-FE is

$$(2) \qquad rCOPUB_{ijt} = \beta_0 \cdot \mathrm{X}_{\mathrm{ijt}}^{\beta_1'} \cdot DIST_{ij}^{\delta} \cdot \sum_{n=-N}^{N} SANC_{n,ijt}^{\gamma_n} \cdot e^{\theta_{ij} d_{ij} + \Psi_{it}(d_i \cdot z_t) + \Psi_{jt}(d_j \cdot z_t)} \cdot \varepsilon_{ijt}.$$

We apply the Ordinary Least Squares (OLS) estimator with varying fixed effect structures as default specification.[2] Equations (1) and (2) are estimated as semi-log specification applying a logarithmic

[2] We consider regression specifications including country-pair fixed effects as a true fixed effects model; specifications controlling for country-level fixed effects are classified as pooled specification with partial fixed effects.

transformation to right-hand-side variables, but we do not log-transform the outcome variable defined as a percentage rate.

Earlier studies have proposed a Poisson Pseudo Maximum Likelihood (PPML) estimator for gravity models and DiD settings (Santos Silva & Tenreyro, 2006; Ciani & Fisher, 2019). We thus also estimate the gravity equation by PPML and, to assess the role of over-dispersion in the data, by a negative binomial (NegBin) estimator. A limitation of the latter is that no true fixed-effect specification is available for panel data (Allison & Waterman, 2002) and that the estimator may be inappropriate when applied to a continuous dependent variable (Bosquet & Boulhol, 2014). As a solution to this problem, we apply PPML and NegBin estimation to co-publication counts (rather than co-publication intensities) to check if treatment effects are sensitive to estimator choice.

As outlined above, we also aim at identifying the transmission channels of sanctions on international knowledge flow. We do so by accounting for effect heterogeneity 1) between country groups (e.g., to test for the role of resentments from some EU countries), and 2) between scientific fields (e.g., to test for the dual use technologies channel). The estimated annual treatment effect parameters ($\sum_{n=-N}^{N} \gamma_n$) are furthermore used in a post-estimation analysis to estimate correlations between their temporal development and general trends in EU-Russia collaborative research funding and academic mobility. These tests for transmission channel are embedded in more general robustness checks that cover alternative subsampling strategies, "pseudo" treatment effect estimates and structural breakpoint tests.

## 4. Data and stylized facts

***Data and variables.*** Scientific co-publications are used as key indicator for knowledge flows, as done in several recent papers on international research collaboration (e.g., Zhang et al., 2018; Wagner et al., 2019). Arguments for the use of scientific co-publications are that 1) scientific publications are the dominant form of diffusing scientific knowledge among the academia (Nelson, 2009) and 2) bibliometric analyses of scientific co-publications have been for long one the most common way of

measuring (international) scientific collaboration (Melin & Persson, 1996). We consider a scientific co-publication to be international if it is authored by at least two authors located in two different countries. An article having authors from several countries will show as a co-authored publication for each country-pair (Makkonen & Mitze, 2016).

All data on scientific co-publications for our main sample covering EU-28 (including the UK) and BRICS countries were gathered on December 2019 from the Web of Science (WoS) Core Collection maintained by Clarivate Analytics and include the Science Citation Index Expanded (SCI-EXPANDED), the Social Science Citation Index (SSCI), the Art & Humanities Citation Index (A&HCI) and the Emerging Sources Citation Index (ESCI). The search procedure utilised the address field and simple Boolean logic, for example, "ADDRESS: (Russia) AND ADDRESS: (Austria)". The BRICS countries include Russia together with Brazil, India, China, and South Africa.[3] The underlying data structure for our EU-BRICS sample thus consists of 33×32=1,056 country pairs for 1995–2018 (=25,344 country pair × year observations). We discuss the caveats related to the use of bibliometric data and how we dealt with them in the online supplementary materials.

For robustness tests we extend the sample to include Belarus and Ukraine.[4] Additional data for Belarus and the Ukraine were gathered in June 2022. When we study the development of EU-Belarus and EU-Ukraine co-publications as reference cases for the EU-Russia development, we design samples in such a way that we replace Russia with either Belarus or Ukraine. This ensures an identical composition of the comparison group as we leave the number of sample observations unchanged. When we study the

[3] BRICS countries are suitable control group candidates as they are comparable to Russia in terms of their economic development level. Importantly, no other BIRCS country introduced economic sanctions against Russia during 2014 –2018.

[4] Belarus and Ukraine as former Soviet Union members share close historical ties to Russia including a similar higher education system, which makes the countries comparable in terms of their scientific knowledge production. Whereas Belarus was not subject to economy-wide sanctions from the EU before 2020 (European Council, 2023b), Ukraine directly suffered from the conflict through the Russian annexation of Crimea and the war in the Donbass and Luhansk regions.

relative development of Russia-Belarus and Russia-Ukraine scientific collaborations, we increase sample size to include 34 countries in each case.

Scientific co-publications are measured at different aggregation levels. Firstly, we collected information on co-publications across all subject categories. For the sample period 1995–2018, this corresponds to a total of 542.33 million publications and 8.60 million international co-publications. One should note that we have purposefully restricted our data to stop at 2018 to exclude the potential confounding effects that the COVID-19 pandemic (that started in 2019) has likely had on scientific collaboration. As a broad definition of knowledge flows may create noise in statistical analysis, secondly, we also collected publications for pre-defined WoS research fields. These include: i) Technology (128 million publications, 1.39 million international co-publications), ii) Physical Sciences (196 million publications, 4.21 million international co-publications), iii) Life Sciences and Biomedicine (208 million publications, 3.30 million international co-publications, and iv) Social Sciences, Arts and Humanities (331 million publications, 3.16 million international co-publications). Thirdly, we compiled a fine-tuned list of 46 WoS subject categories closely related to the EU export restrictions for dual use technologies (152 million publications, 2.21 million international co-publications). Matching between our "Dual Use Category" and WoS subject categories was made based on Scalia et al.'s (2017) description of dual use technologies (Table A1 in the online supplementary materials).

Our key outcome variable is the international co-publication intensity for a given country pair *ij* at time *t*, which is defined as the number of international co-publications $(COPUB_{ijt})$ expressed as percentage share of the average number of total publications $(Pub)$ in countries *i* and *j* at time *t*:

$$rCOPUB_{ijt} = \left(\frac{COPUB_{ijt}}{(PUB_{it}+PUB_{it})/2}\right) \cdot 100. \quad (3)$$

As shown in Table 1, the sample average of the international co-publication intensity is 1.27% but varies between 0 and 18% across country pairs. Significant differences in the shares of international co-publications can be observed across scientific fields, with the highest average international co-

publication intensity being observed for Physical Sciences (1.92%) followed by the Dual Use Category (1.33%). In the latter category, the maximum value for the international co-publication intensity can be up to 59% underlining the relative importance of international knowledge flows for scientific progress in this research area. One advantage of using a relative measure of co-publication activity ($rCOPUB_{ijt}$) rather than co-publication counts for estimation is that $rCOPUB_{ijt}$ is tested to be stationary using panel unit root tests (but not $COPUB_{ijt}$, see Table C2 in the online supplementary materials), which limits the risk of estimation biases from spurious regressions.

Table 1: Summary statistics for variables used in gravity model estimations

| Variable | Source | Obs. | Mean | S.D. | Min. | Max. |
|---|---|---|---|---|---|---|
| **Co-publication intensity (in %)** | WoS | 25,344 | 1.27 | 1.57 | 0 | 18.37 |
| > Dual Use Category | WoS | 25,344 | 1.33 | 2.02 | 0 | 59.60 |
| > Technology | WoS | 25,344 | 0.85 | 1.16 | 0 | 15.86 |
| > Physical Sciences | WoS | 25,344 | 1.92 | 2.47 | 0 | 31.93 |
| > Life Sciences & Biomedicine | WoS | 25,344 | 1.11 | 1.52 | 0 | 13.03 |
| > Social Science, Arts & Humanities | WoS | 25,344 | 0.58 | 1.28 | 0 | 68.29 |
| **Co-publication count** | WoS | 25,344 | 328.58 | 800.04 | 0 | 12,403 |
| > Dual Use Category | WoS | 25,344 | 87.32 | 199.37 | 0 | 5973 |
| > Technology | WoS | 25,344 | 55.09 | 151.27 | 0 | 5670 |
| > Physical Sciences | WoS | 25,344 | 166.14 | 337.50 | 0 | 4579 |
| > Life Science & Biomedicine | WoS | 25,344 | 130.44 | 339.36 | 0 | 5327 |
| > Social Science, Arts & Humanities | WoS | 25,344 | 12.49 | 43.63 | 0 | 899 |
| **Publication count** | WoS | 25,344 | 19,392.1 | 34,473.9 | 32 | 383,875 |
| > Dual Use Category | WoS | 25,344 | 6,002.7 | 13,214.3 | 2 | 176,338 |
| > Technology | WoS | 25,344 | 5,042.9 | 11,892.3 | 3 | 167,986 |
| > Physical Sciences | WoS | 25,344 | 7,740.7 | 14,444.4 | 1 | 157,945 |
| > Life Sciences & Biomedicine | WoS | 25,344 | 8,197.3 | 12,567.5 | 14 | 114,366 |
| > Social Science, Arts & Humanities | WoS | 25,344 | 1,308.4 | 2,630.9 | 0 | 22,409 |
| International trade intensity (in %) | UNCTAD | 25,344 | 2.14 | 3.97 | 0 | 41.01 |
| Per-capita GDP (in levels, PPP) | UNESCO | 25,344 | 28,562.6 | 15,706.8 | 2,036.8 | 97,864.2 |
| Geographical Distance (in km) | GW | 25,344 | 2,936.63 | 2,943.02 | 62 | 16,911 |

*Notes:* Data for the main sample covering the EU-28 countries and the five BRICS countries (Brazil, Russia, India, China, and South Africa). WoS = Web of Science. The international trade intensity is defined as sum of exports and imports for

each country pair relative to the overall trade volume of the countries (in %). *Source* (for international trade data): http://unctadstat.unctad.org/. Per-capital GDP levels in Purchasing Power Parities (PPP) are measured in 2011 US Dollar prices. *Source* (for GDP data): http://data.uis.unesco.org/Index.aspx; GW = Gleditsch and Ward (1999) available at: http://ksgleditsch.com/data-5.html.

***Stylized facts.*** Panel A of Figure 1 compares the relative development of EU-Russia co-publications with the respective figures for the remainder of BRICS countries. The panel shows a country's overall co-publication intensity with the EU, indexed to 100 in 2013. Annual co-publication intensities were persistently higher for the EU-Russia scientific relationship during the 1990s and early 2000s compared to those for the remainder of BRICS countries. However, EU-BRICS co-publication intensities have shown a steeper growth trend compared to the EU-Russia development after 2014. This gives a first indication of potentially detrimental effects of economic sanctions on knowledge flows. Panel B of Figure 1 compares the temporal development in field-specific co-publications between the average time periods of 2014–2018 and 2009–2013 for EU-Russia and EU-BRICS. Growth in co-publication shares after the start of the Ukraine crisis is generally lower in the EU-Russia treatment group compared to the respective development for EU-BRICS. This gap is particularly large for the fields of i) Dual Use Category, ii) Physical Sciences and iii) Life Sciences and Biomedicine. More visualizations of the aggregate and field-specific development of EU-Russia and EU-RICS co-publications are given in Figures C6 and C7 in the online supplementary materials. Further, we provide descriptive evidence from a synthetic control method approach, which accounts for different time trends in co-publication intensities prior to the imposition of sanctions in the online supplementary materials.

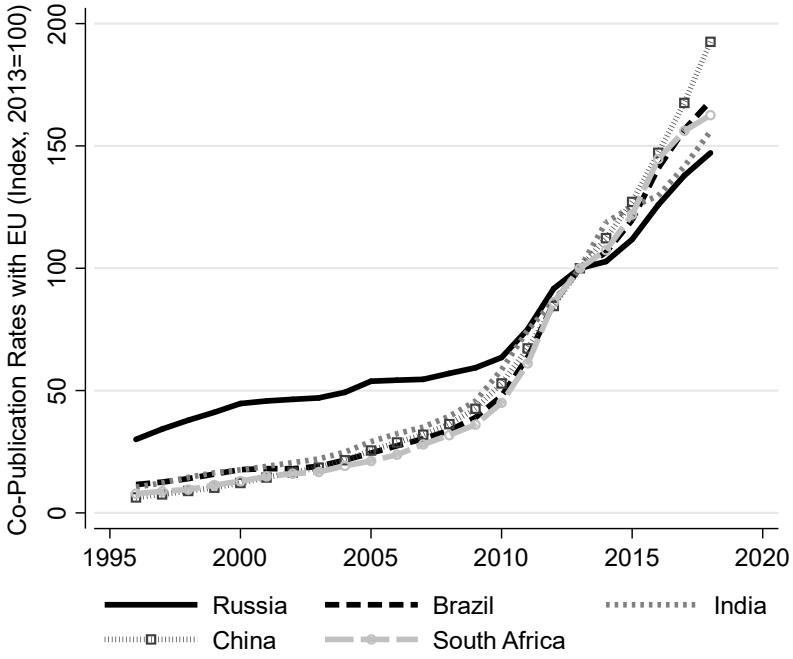
## 5. Estimation results

***Aggregate findings.*** Table 2 reports estimated treatment effects for alternative gravity model specifications that vary in terms of included control variables, fixed effect structure and outcome variable used. Next to estimates for the scientific co-publication intensity as key outcome variable, in column (I) we additionally estimate a gravity model of international trade flows as a reference case. As expected, the start of the Ukraine crisis and the associated sanctions and countersanction in 2014 led to a significant drop in the EU-Russia trade intensity, which declined by, on average, 0.58%-points during the treatment period 2014–2018. Evaluated against the average international trade intensity between EU countries

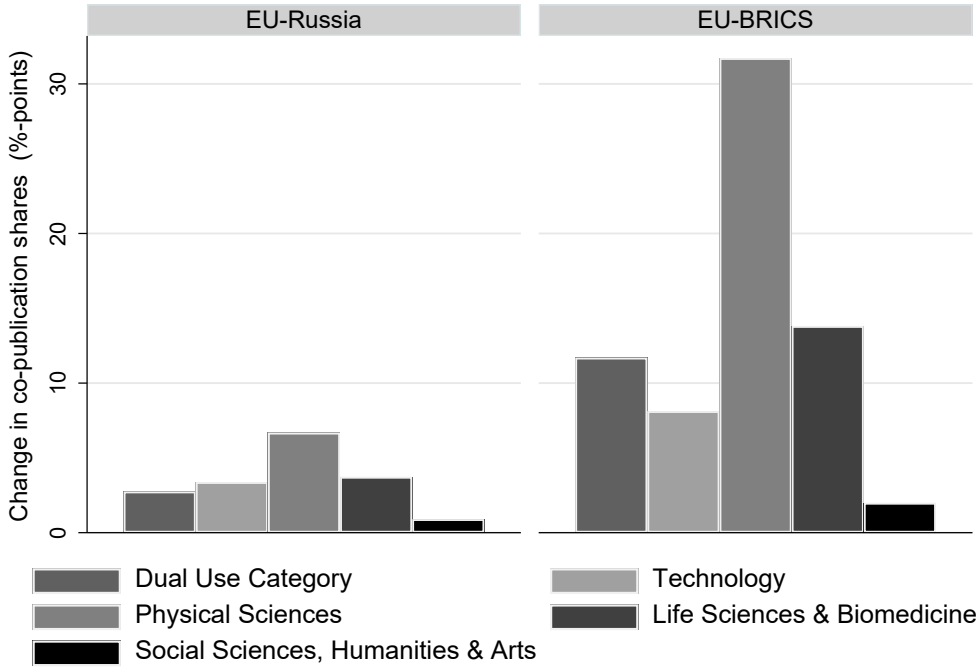
and Russia of 3.7% before the start of the Ukraine crisis, in line with earlier studies, we find that sanctions have reduced annual bilateral trade by approx. 16% (Fritz et al., 2017; Crozet and Hinz, 2020).

Figure 1: Stylized facts for temporal development of EU-BRICS co-publication intensities (aggregate and by scientific fields)

Panel A: EU-BRICS co-publication intensities




Panel B: Change in co-publication shares 2014–18 vs. 2009–13




*Notes:* Data based on the WoS Core Collection maintained by Clarivate Analytics. Annual co-publication intensities (Panel A) are defined as the sum of co-publications between the EU and each BRICS country divided by the total number of publications in each country. Co-publications shares (Panel B) for scientific fields are calculated as percentage share of field-specific co-publications in a country's total publication count per year. Values are averaged for the two time periods 2009-2013 and 2014-2018.

If we compare the gravity model estimates of trade flows with those of international knowledge flow, column (II) in Table 2 indicates that the scientific co-publication intensity likewise experienced a significant decline during the sanctions period. Regarding the effect size, the pooled OLS specification points to a 0.72%-points decline in EU-Russia co-publication intensity, which translates into 42% reduction in knowledge exchange compared to the last pre-sanctions year 2013 (for an average co-publication intensity of 1.64%). The pooled OLS results further highlight the working of the basic gravitational forces on international co-publication activity, particularly geographical distance. In line with earlier work (Peri, 2005; Picci, 2010), we find that international knowledge flows decline with increasing geographical distance although the effect is smaller compared to the case of international goods trade between sample countries.

Once we account for the full MD-FE structure, the reduction in the international co-publication activity is estimated to be 0.61%-points (column (IV)), which translates into a reduction in EU-Russia co-publication activity by approx. 37% compared to 2013 and by 55% compared to average co-publication intensity of 1.1% for the total pre-treatment period 1995–2013. For the PPML estimator in column (V) we get a moderately higher treatment effect of 100×(exp(-1.378)-1)=-74% for this period. Negative treatment effects are also found for the PPML and NegBin estimator if we use co-publication counts as outcome variable. While the different estimators thus jointly point to significant treatment effects in the baseline gravity specification, for the remainder analysis, we rely on the FEM with MD-FE structure as a robust and conservative estimator of treatment effects.

Table 2: Gravity model estimates for treatment effects of sanctions on EU-Russia scientific co-publication intensity and co-publication count

| Estimator | POLS | POLS | FE | FE | PPML | PPML | NegBin |
|---|---|---|---|---|---|---|---|
| Outcome | International Trade Intensity | Co-Publication Intensity | Co-Publication Intensity | Co-Publication Intensity | Co-Publication Intensity | Co-Publication Count | Co-Publication Count |
| Coefficient (×100) | (I) | (II) | (III) | (IV) | (V) | (VI) | (VII) |
| Dummy EU-Russia County Pairs | 1.207*** (*t*-stat: 6.09) [CI: 0.818, 1.596] | 0.211*** (*t*-stat: 5.64) [CI: 0.137, 0.284] | | | | | |
| Geographical Distance (*DIST*) | -2.876*** (*t*-stat: -49.55) [CI: -2.990, -2.763] | -0.915*** (*t*-stat: -43.86) [CI: -0.956, -0.009] | | | | | |
| Economic Sanctions (*SANC*) | -0.582*** (*t*-stat: -3.20) [CI: -0.939, -0.002] | -0.709*** (*t*-stat: -11.57) [CI: -0.829, -0.589] | -0.734*** (*t*-stat: -10.81) [CI: -0.867, -0.600] | -0.610*** (*t*-stat: -6.40) [CI: -0.798, -0.423] | -1.378*** (*t*-stat: -2.80) [CI: -2.343, -0.413] | -1.629*** (*t*-stat: -5.33) [CI: -2.229, -1.030] | -1.401*** (*t*-stat: -3.30) [CI: -2.233, -0.569] |
| Observations | 25,344 | 25,344 | 25,344 | 25,344 | 25,344 | 25,344 | 25,344 |
| Control Variables (GDP, Pub, Trade) | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Country FE | Yes | Yes | — | — | — | — | Yes |
| Country-Pair FE | — | — | Yes | Yes | Yes | Yes | — |
| Country × Time FE | — | — | — | Yes | Yes | Yes | Yes |

*Notes:* * $p<0.1$; ** $p<0.05$; *** $p<0.01$. POLS = Pooled Ordinary Least Squares, FEM = Fixed Effects panel model, PPML = Poisson Pseudo Maximum Likelihood estimator NegBin = Negative binomial panel model; *t*-statistics in round brackets and 95% confidence intervals (CI) in square brackets with underlying standard errors are clustered at the country-pair level; sample period 1995–2018.

***Effect heterogeneity by country groups.*** Results presented in Table 3 extend the baseline results in two important dimensions. First, as shown in column (II) of Table 3, we reduce the comparison group by excluding EU country pairs. This sample reduction is motivated by the fact that the intra-EU co-publication activities may have intensified over time alongside the progress of European integration and the creation of a European Research Area (ERA), which may lead to an over-estimation of treatment effects of EU-Russia sanctions given this strict benchmark. Indeed, estimated treatment effects for the subsample excluding intra-EU country pairs become smaller and amount to an approximately 0.17%-point reduction for the sub-sample estimates. Importantly, however, the effect stays statistically significant at the 5% critical level. It translates into a decline in international co-publication activity by approx. 15% when comparing the EU-Russia to EU-BRICS and BRICS-BRICS (excluding Russia) scientific knowledge collaborations. We take this 15% reduction as lower bound estimate for a latent true sanctions effect, while the 55% reduction for the full sample likely constitutes an upper bound.

Second, we estimate disaggregate treatment effects for subgroups of EU-28 countries. As outlined above, this allows us to test for the role of the resentment channel in the link between economic sanctions and knowledge flows. Specifically, we group EU countries into those which 1) were strongly in favour of sanctions, and 2) had a generally negative attitude towards Russia (i.e., "hawkish" EU countries) compared to "dovish" EU countries being against sanctions and more friendly towards Russia (the categorization of EU countries based on two complementary data sets is shown Table C1 in the online supplementary materials). Alternatively, we classify countries by their historical ties to Russia before the fall of the iron curtain. We, accordingly, split the EU-28 group into a Western subgroup including the EU-15 countries prior to the Eastern enlargement in 2004 (plus Malta and Cyprus; EU-17) and the CEEC-11 subgroup comprising Central and Eastern European countries that were historically a part of the Soviet Union or the Warsaw Pact (plus Croatia and Slovenia as part of the former Yugoslavia).

Table 3: Treatment effects heterogeneity across EU country groups

| Sample | All country pairs | Excluding intra-EU country pairs |
|---|---|---|
| Coefficient (×100) | (I) | (II) |
| Treatment group: Russia and … | | |
| EU-28 countries | -0.610*** | -0.170** |
| | (*t*-stat: -6.40) | (*t*-stat: -2.10) |
| | [CI: -0.798, -0.423] | [CI: -0.330, -0.010] |
| EU countries† "Pro-sanctions" and | -0.655*** | -0.335*** |
| "Negative" attitude towards Russia | (*t*-stat: -5.67) | (*t*-stat: -3.15) |
| | [CI: -0.882, -0.429] | [CI: -0.702, -0.114] |
| EU countries‡ "Against-sanctions" and | -0.585*** | -0.079 |
| "Positive/Neutral" attitude towards Russia | (*t*-stat: -5.53) | (*t*-stat: -0.89) |
| | [CI: -0.793, -0.378] | [CI: -0.257, 0.097] |
| EU-17$ countries | -0.665*** | -0.297*** |
| | (*t*-stat: -6.71) | (*t*-stat: -3.24) |
| | [CI: -0.859, -0.470] | [CI: -0.478, -0.117] |
| CEEC-11§ countries | -0.502*** | 0.067 |
| | (*t*-stat: -3.89) | (*t*-stat: 0.78) |
| | [CI: -0.754, -0.249] | [CI: -0.102, 0.235] |
| Observations | 25,344 | 7,200 |
| Control Variables | Yes | Yes |
| Time FE | Yes | Yes |
| Country-Pair FE | Yes | Yes |
| Country × Time FE | Yes | Yes |

*Notes:* * $p<0.1$; ** $p<0.05$; *** $p<0.01$. † Denmark, Estonia, Finland, Germany, Poland, Sweden, UK, Netherlands, Belgium, and Luxemburg; ‡ the remaining EU countries not covered by †; $ Austria, Belgium, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain, Sweden, and the UK; § the remaining EU countries not covered by $. Estimates are based on FEM panel model with robust standard errors as in Table 2, Column IV; *t*-statistics in round brackets and 95% confidence intervals in square brackets with underlying standard errors being clustered at the country-pair level; sample period 1995–2018.

The results in Table 3 for regressions with separate treatment groups show the following picture: the negative treatment effect of sanctions is stronger for the countries with a "hawkish" attitude towards Russia ("Pro-sanctions" and "Negative" attitude). Likewise, the effect is stronger for the subgroup of EU-17 countries compared to CEEC-11 countries. Coefficients differences in both cases are tested to be statistically significant. If we further exclude intra-EU scientific collaborations as strict benchmark, we even find evidence for qualitatively positive (though statistically insignificant) treatment effects

during the sanctioning period 2014–2018 between i) "dovish" countries ("Against-sanctions" and "Positive/Neutral" attitude) and Russia, and ii) the CEEC-11 subgroup and Russia. Very similar effects as for the CEEC-11 subgroup are also observed for the subgroup of EU-5 countries sharing a common territorial border with Russia (details are given in Table E1 in the s online supplementary materials). Again, group differences ("hawkish" vs. "dovish" and EU-17 vs. CEEC-11) for these subgroup estimates are tested to be statistically significant. We take these disaggregated results as evidence that resentments play a potential role for the development of international knowledge flows as particularly "hawkish" Western EU countries have reduced scientific collaboration with Russia after the start of the Ukraine crisis. Recent studies on the internationalisation of Russian science align with our subgroup findings as they provide evidence on the role of historical ties in Russian international collaboration activity and on changes in science internationalisation after the start of the Ukraine crisis between Russia and EU countries (see e.g., Kozak et al., 2015; Karaulova et al., 2016; Matveeva et al., 2022).

As a robustness test, we run a series of sub-sample estimates which subsequently leave out one (EU or BRICS) country from the sample. The logic of these "leave one out"-tests is to see if the negative sanctions impact on international scientific collaborations describes a universal treatment effect or if it is (directly or indirectly) driven by strong changes in some few bilateral co-publication intensities. However, the coefficient for the treatment indicator remains negative and statistically significant in all cases (Tables E2 and E3 in the online supplementary materials). Another type of robustness tests relates to the estimation of "pseudo" treatment effects, which investigate if the observed negative treatment effects during 2014–2018 also hold for country pairs included in the comparison group and are, thus, only a statistical artefact. The findings support the specific negative development of EU-Russia co-publication intensity under sanctions since we find positive "pseudo" treatment effects for the EU and the remainder BRICS countries, Belarus, and Ukraine (Table E4 in the online supplementary materials). Similarly, "pseudo" treatment effects for collaboration between Russia and these countries are in almost all cases positive. We take this as empirical support that the estimated negative

treatment effects between the EU and Russia are not just a reflex of latent confounding global trends but can be specifically attributed to the Ukraine crisis and the imposition of economic sanctions.

***Effect heterogeneity by scientific fields.*** Table 4 reports treatment effects for the EU-Russia co-publication intensity by scientific fields. The results for the full sample of all country pairs (column (I)) and the subsample excluding intra-EU county pairs in column (II) point to significant negative effects of sanctions in most fields considered. Only for Life Sciences and Biomedicine the subsample estimates in column (II) show statistically insignificant effects. Again, the difference in effect size between the full sample and the subsample points to the fact that including intra-EU collaborations as part of the comparison group constitutes a strict benchmark for measuring the causal effect of EU-Russia sanctions on knowledge flows and should only be regarded as upper-bound estimate for this sanctions effect. If we further split EU countries into "hawkish" and "dovish" subgroups, the field-specific results again point to stronger detrimental effects for the group of "hawkish" EU countries. Group differences are tested to be statistically significant.

Regarding scientific co-publications in the Dual Use Category, which is most closely linked to the EU trade sanctions, we find a reduction in the EU-Russia co-publication intensity of between 0.29 and 0.71 %-points. Evaluated against the pre-treatment average of 1.37% for the treatment group, this reduction translates into a relative decline in international co-publication activity of between 23% and 52% caused by the sanctions. The corresponding reductions for the pre-defined WoS scientific fields are: Technology (between 11% and 53%), Physical Sciences (between 41% and 80%), Life Sciences and Biomedicine (80%, but only statistically significant for the full sample including intra-EU country pairs) and Social Sciences, Arts & Humanities (between 48% and 66%).

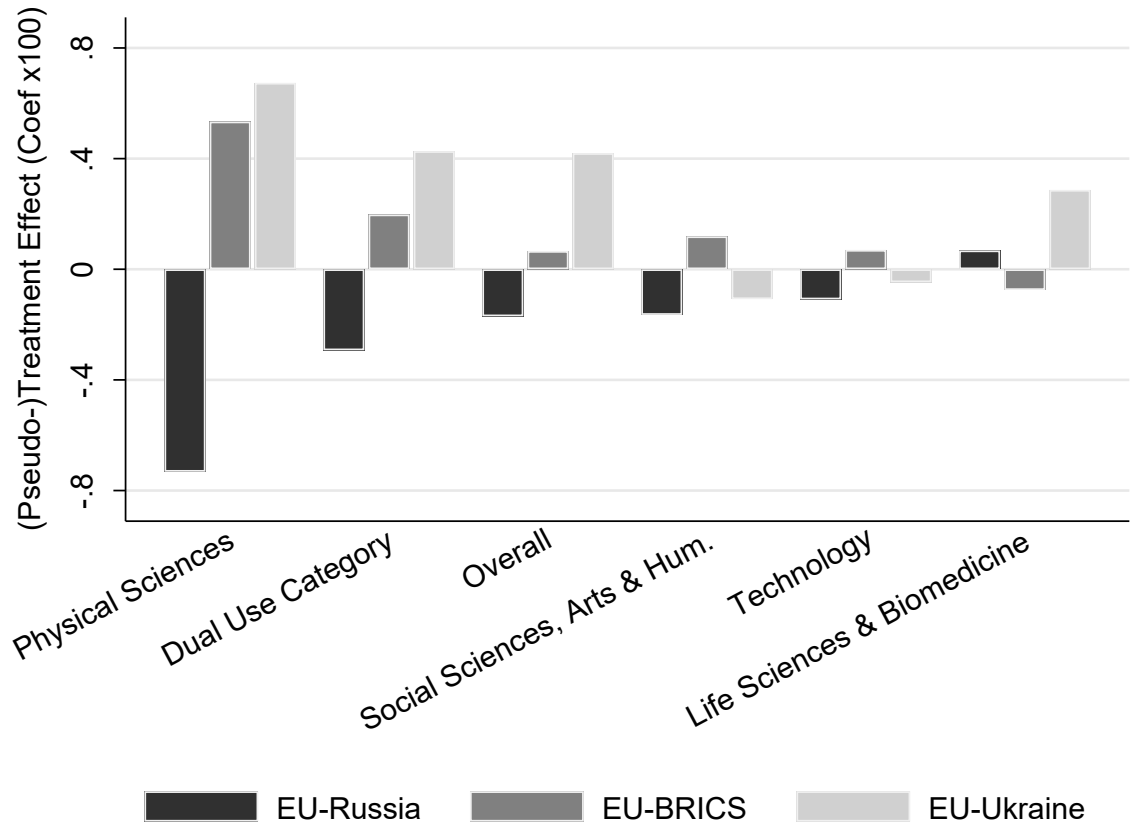
Table 4: Estimated treatment effects of EU-Russia sanctions by publication fields

| Included EU countries | EU-28 | EU-28 | "Pro-sanctions" and "Negative" attitude† | "Against-sanctions" and "Positive/Neutral" attitude‡ |
|---|---|---|---|---|
| Sample | All country pairs | Excluding intra-EU country pairs | Excluding intra-EU country pairs | Excluding intra-EU country pairs |
| Coefficient (x100) | (I) | (II) | (III) | (IV) |
| Dual Use Category | -0.712*** | -0.293*** | -0.499*** | -0.180** |
| | (*t*-stat: -7.38) | (*t*-stat: -4.43) | (*t*-stat: -4.59) | (*t*-stat: -2.57) |
| | [CI: -0.902, -0.523] | [CI: -0.423, -0.163] | [CI: -0.711, -0.286] | [CI: -0.318, -0.042] |
| Technology | -0.526*** | -0.109** | -0.249*** | -0.032 |
| | (*t*-stat: -6.69) | (*t*-stat: -2.02) | (*t*-stat: 2.84) | (*t*-stat: -0.55) |
| | [CI: -0.680, -0.371] | [CI: -0.216, -0.003] | [CI: -0.420, -0.077] | [CI: -0.147, 0.083] |
| Physical Sciences | -1.436*** | -0.732*** | -0.986*** | -0.593*** |
| | (*t*-stat: -6.58) | (*t*-stat: -6.79) | (*t*-stat: -6.56) | (*t*-stat: -5.14) |
| | [CI: -1.863, -1.008] | [CI: -0.945, -0.520] | [CI: -1.279, -0.691] | [CI: -0.820 ,-0.366] |
| Life Sciences & Biomedicine | -0.549*** | 0.068 | -0.068*** | 0.142** |
| | (*t*-stat: -6.77) | (*t*-stat: 1.22) | (*t*-stat: -0.93) | (*t*-stat: 2.42) |
| | [CI: -0.708, -0.390] | [CI: -0.042, 0.179] | [CI: -0.211, 0.075] | [CI: 0.026, 0.257] |
| Social Sciences, Arts & Humanities | -0.225*** | -0.165*** | -0.259*** | -0.113*** |
| | (*t*-stat: -3.87) | (*t*-stat: -3.38) | (*t*-stat: -3.22) | (*t*-stat: -2.63) |
| | [CI: -0.339, -0.111] | [CI: -0.261, -0.069] | [CI: -0.417, -0.101] | [CI: -0.197, -0.028] |
| Observations | 25,344 | 7,200 | 7,200 | 7,200 |
| Control Variables | Yes | Yes | Yes | Yes |
| Time FE | Yes | Yes | Yes | Yes |
| Country-Pair FE | Yes | Yes | Yes | Yes |
| Country × Time FE | Yes | Yes | Yes | Yes |

*Notes:* * $p<0.1$; ** $p<0.05$; *** $p<0.01$. † Denmark, Estonia, Finland, Germany, Poland, Sweden, UK, Netherlands, Belgium, and Luxemburg; ‡ the remaining EU countries not covered by †. Estimates are based on Fixed Effects panel model (FEM); *t*-statistics in round brackets and 95% confidence intervals in square brackets with underlying standard errors being clustered at the country-pair level; sample period 1995–2018.

Again, contrary to the field-specific negative treatment effects for EU countries and Russia, we find statistically insignificant or even positive "pseudo" treatment effects when we estimate the field-specific development between EU countries and the remainder BRICS countries or Ukraine (Figure 2). Results for EU-Belarus scientific collaborations are like the EU-Ukraine case, but do not cover all scientific fields (full estimation results are reported in Table E5 in the online supplementary materials). The general picture shown in Figure 2 is thus that the negative development of the EU-Russia co-publication intensity (overall and by scientific fields) is a unique trend and very likely associated to the imposition of sanctions and countersanctions during the Ukraine crisis.

Figure 2: Estimates for "pseudo" treatment groups by scientific fields




*Notes:* Estimates based on sample excluding intra-EU country pairs. Estimates for EU-Russia treatment effects are taken from column (II) of Table 4. Effects for the overall development of scientific co-publications for EU-BRICS (excluding Russia) and EU-Ukraine are taken from Table E4 in the online supplementary materials; detailed field-specific estimation results for the pseudo-treatment effects for EU-BRICS (excluding Russia) and EU-Ukraine are reported in Table E5 in the online supplementary materials.

***Breakpoint tests and dynamic treatment effects.*** We run dynamic treatment models to test for early anticipation or gradual phasing-in effects. Early anticipation effects can be associated with a decline in the EU-Russia co-publication intensity before the actual start of the Ukraine crisis and sanctions in 2014. If we find evidence for such effects, causal interpretations of sanctions effect need to be done very carefully. We approach the issue in two ways. First, we run tests for structural breakpoints in the co-publication data together with linked break date estimations (Bai and Perron (1998; 2003; Ditzen et al., 2021). Tests are applied to different sample settings and are organized as 1) a sequential F-test with the null hypothesis of $s$ breaks versus the alternative of $s+1$ breaks and 2) estimates of the timing of the identified breaks. Second, we estimate annual treatment effects for EU-Russia co-publication intensities in a flexible DiD manner according to equation (2).

For different sample settings (all country pairs, subsamples excluding intra-EU pairs) we get evidence for three breakpoints in the early 2002 (or 2000 in the case of subsample estimates), 2010 and 2015. Using these breakpoints, we then run an incremental DiD estimator, which includes binary treatment dummies for EU-Russia collaboration during the three different time periods (2002–2018, 2010–2018, 2015–2018). Including all three treatment dummies simultaneously in the gravity equation allows us to compute i) a baseline effect after 2002 (Regime 1) and ii) two additional (marginal) treatment effects for 2010–2018 (Regime 2) and 2015–2018 (Regime 3), respectively.

As it is reported in detail in Table E6 in the online supplementary materials, we find no statistically significant baseline treatment effect for the period after 2002. This changes for the period marked by the second breakpoint in 2010. where we find a decline in the aggregate co-publication intensity between the EU and Russia *vis-à-vis* the included comparison groups. While this points to an underlying longer run trend development,[5] importantly, we also obtain a statistically significant coefficient

[5] The presence of a structural break in the EU-Russia co-publication activity around 2010 may relate to the consequences of the global financial and economic crisis of 2008/09 in Russia together with the financial and political repercussion of the Russia-Georgia war of 2008. The war accelerated Russia's financial crisis (Desai, 2010) and derailed the science

for the additional treatment dummy for 2015–2018 pointing to another structural break in the data after 2014 and, hence, a dynamic decline of EU-Russia co-publication activity after the start of the Ukraine crisis.

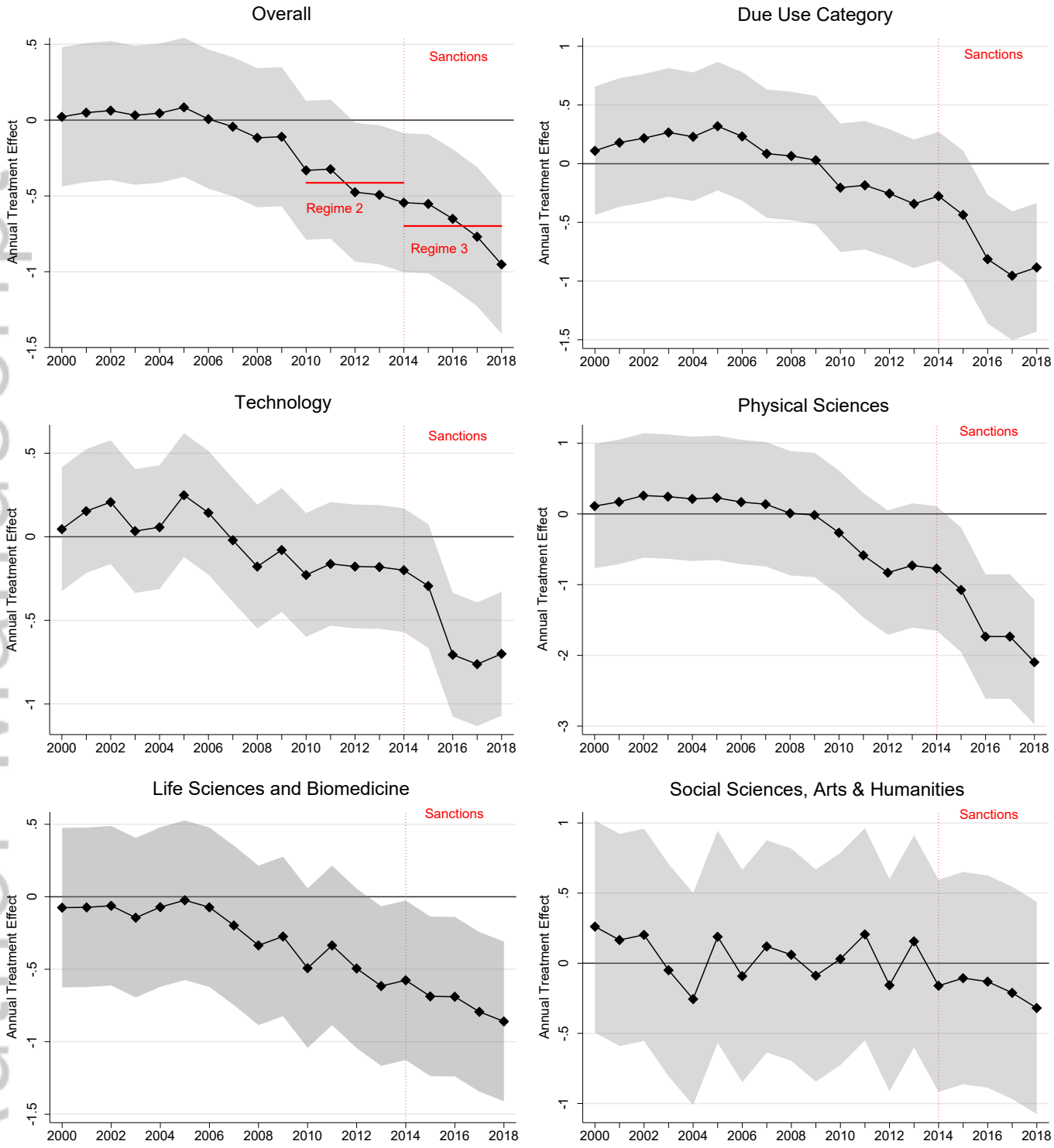
Differences in total treatment effects for Regime 2 and Regime 3 are visualized in the upper left panel of Figure 3 together with estimated annual treatment effects from the flexible DiD approach according to equation (2). Annual treatment effects are computed against the baseline period 1995–1999 and are obtained for the FEM estimator with MD-FE structure.[6] While the figure shows that annual treatment effects turn significantly negative after 2010, it also clearly highlights that the size of treatment effect strongly grows over time (particularly from 2015 onwards, i.e., the timing of the third identified structural breakpoint in the data). The field-specific annual treatment effects in the remainder panels of Figure 3 show even more clearly a decline in effects around the start of sanctions in 2014.

Taking a closer look at the development of the annual coefficients across the different scientific fields, for 3 out of 5 cases (Dual Use Category, Technology, and Physical Sciences) we obtain statistically significant negative treatment effects associated with the start of the imposition of sanctions in 2014. While no systematic treatment effects can be detected prior to 2014, effects turn persistently negative after the start of sanctions and, in line with the overall development, are observed to grow over time. This latter observation from the dynamic DiD estimates indicates that the negative long-run consequences of sanctions on international scientific knowledge flows may be even larger than those reported by the static DID model specifications in Tables 2 to 4.

diplomacy relations between the West and Russia (Bertelsen, 2019). One should note, though, that the estimated effect for Regime 2 partly overlaps with the Ukraine crisis in 2014 and thus also captures a potential sanctions effect.

[6] Given that data by scientific fields have higher shares of zero entries or low numbers of co-publications for country pair-year combinations, dynamic treatment plots shown in Figure 3 are estimated for the full sample.

Figure 3: Estimated annual treatment effects on knowledge flows (overall and by scientific fields)




*Notes:* Grey areas indicate 95% confidence intervals for yearly treatment effects (black dot); underlying estimates are based on Fixed Effects panel model (FEM) including controls, time-, country-pair and country × time fixed effects (as in Column (IV) of Table 2); sample period for estimation 1995–2018 (EU-28 incl. all country pairs). Plotted reference lines for the overall sample indicate the estimated treatment effect regimes according from column (I) in Table E6 (online supplementary materials).

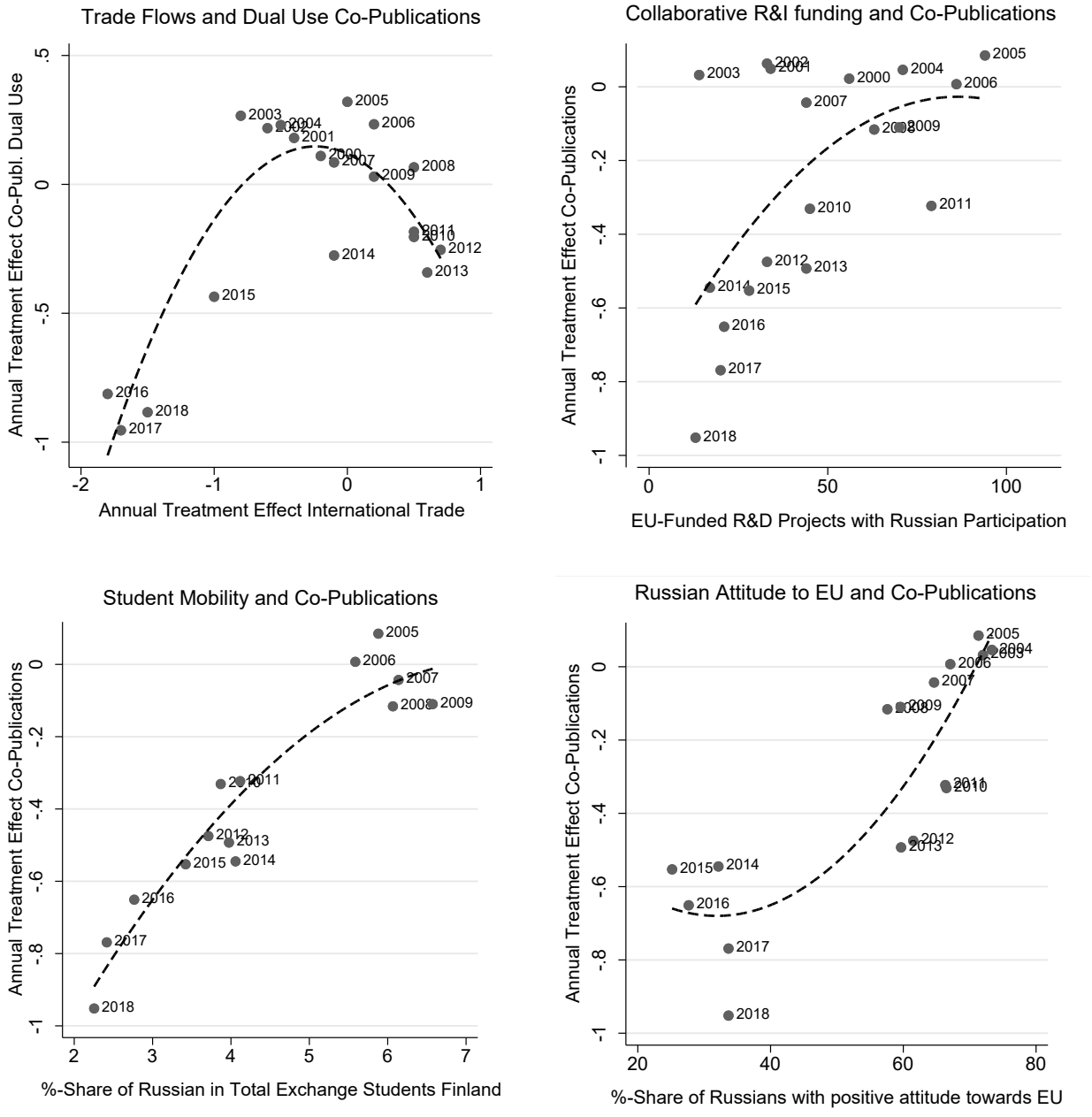
For Life Sciences and Biomedicine, the annual treatment effects in Figure 3 indicate a relative decline in EU-Russia scientific collaboration already throughout the late 2000s. One potential reason here is that this scientific field is driven by deepening European integration in research and a resulting dynamically growing "Europeanisation" of the international co-publication activity (Mattsson et al., 2008). This result is also in line with the estimated effects for different sample settings as shown in Table 4. For Social Sciences, Arts & Humanities the annual coefficient plots point to negative though statistically insignificant treatment effects when evaluated against the baseline period 1995–1999.

Taken together, the structural breakpoint tests and the estimation of annual treatment effects show that the start of the sanction period exacerbated the negative development of scientific knowledge flows – even if a tendency for gradually declining co-publication intensities prior to 2014 was visible in the data. The latter aspect points to the fact that highly aggregated macroeconomic variables can hardly be seen as strictly exogenous but inherently reflect long-run developments (beyond political factors). This is particularly relevant for scientific knowledge production based on perennial research projects. Despite these trends, however, all our estimates point to a significantly negative (spiralling) effect of the Ukraine crisis and the imposition of economic sanctions on EU-Russia knowledge flows.

***Post-estimation analysis of transmission channels.*** In Figure 4, we finally correlate the estimated annual treatment effects with time-series indicators for transmission channels of the sanctions effect on international knowledge flows. Although such simple scatter plots should not be regarded as a strict causal investigation, the revealed correlation patterns may help us to further assess the relevance of different transmission channels for the observed decline in the EU-Russia co-publication intensity. The upper left panel in Figure 4 looks at the trade-based transmission channel by correlating two types of annual treatment effects, namely those obtained for the co-publication intensity in the Dual Use Category (as shown in Figure 3) and for the international trade intensity (as a dynamic version of the benchmark estimates reported in column (I) of Table 2). The reported quadratic fit regression line points to a clear co-evolution of declining EU-Russia co-publication and trade intensities during

the treatment period. We observe a clear cluster of highly negative annual treatment effects for both knowledge and trade flows during the period 2016–2018, i.e., after the start of the Ukraine crisis and the imposition of sanctions and countersanctions.

Figure 4: Post-estimation correlations on the transmission channels of sanctions on knowledge flows




*Notes:* Estimated annual effects for the co-publication intensity are taken from Figure 3 (overall, Dual Use Category); estimated annual treatment effects for the EU-Russia trade intensity are shown in Figure E1 in the online supplementary materials. Data on Russian participation in EU-funded R&I projects are taken from Figure C4; the share of Russian in total exchange students in Finland is based on data shown in Figure C2; the share of Russian with positive attitude towards the EU are annual averages for the monthly data shown in Figure C1 (online supplementary materials).

A similar pattern can be observed when we correlate the annual treatment effects for the overall co-publication intensity and the temporal development of EU-funded R&I projects with Russian collaboration. The plotted quadratic trend line in the upper right panel of Figure 4 indicates a general positive correlation between estimated annual treatment effects and the participation of Russian researchers in the EU FPs and the H2020 programme. After 2013, i.e., the start of H2020, the Russian participation drops further. Similar correlations can also be observed when we correlate the annual treatment effects for the EU- Russia co-publication intensity with 1) the degree of student mobility between Russia and Finland as an exemplary EU country with a traditionally vivid academic exchange and 2) the share of Russians with a positive attitude towards the EU.[7] Taken together, the correlation analyses underline the potential role of the different transmission channels identified in the literature (Section 2) to explain the decline in EU-Russia scientific collaboration after the start of the Ukraine crisis and the imposition of sanctions and countersanctions. Future research should further integrate these factors (particularly academic/researcher mobility and collaborative funding) into the gravity model framework to thoroughly test for the nature of observed treatment effects.

## 6. Discussion and Conclusion

Since the start of the Ukraine crisis, EU-Russia relations have entered the most profound geo-political crisis after the end of the Cold War. While earlier research has already highlighted the detrimental effects of economic sanctions and countersanctions on the movement of goods (i.e., trade), capital (e.g., FDI) and people, the question if sanctions have also affected the flows of knowledge between the EU and Russia has thus far remained an open one. We argue that a focus on international knowledge flows is well deserved given their role for the diffusion of new technologies and innovations as driver for economic growth and development. While EU-Russia research collaborations have

[7] Unfortunately, we could not find comparable long time series on the attitude of EU citizens towards Russia. The Eurobarometer (2016; 2018) data used to categorize EU countries based on the attitude towards Russia is only available after the start of sanctions.

been fully stalled as part of the EU sanction package after the Russian military invasion of Ukraine in February 2022, our focus here is on studying the impact of sanctions during the first years of the Ukraine crisis, when research collaborations took place in a grey zone, i.e., were not explicitly ruled out but indirectly affected through different channels.

Our results provide empirical evidence that EU-Russia co-publication activities have significantly lost ground since the imposition of sanctions in 2014 relative to the scientific collaboration activities of comparison groups, such as co-publications between EU countries and the remainder BRICS economies. Estimating treatment effects by scientific fields also helped us to investigate the likely transmission channels of sanctions on knowledge flows. To this end, we have constructed a category for scientific publications in the Dual Use Category, which are directly related to the EU export restrictions of dual use goods. We find a clear negative treatment effect for this category, which is larger than the estimated aggregate effect. Likewise, we find larger treatment effects for the subgroup of EU countries with a "hawkish" attitude towards Russia (i.e., countries that are "Pro-sanctions" and have a "Negative" attitude towards Russia) compared to their opposites, the "dovish" EU countries. This may point to the role of resentments in the development of EU-Russia research collaborations.

Negative treatment estimates for EU-Russia co-publication intensity are found for static and dynamic regressions. Using the obtained time pattern of annual treatment effect, we find that effects correlate with the development of EU-funded R&I projects with Russian collaboration and academic mobility between Russia and EU countries such as Finland. These additional findings point to further transmission channels of economic sanctions on knowledge flows. When we estimate annual treatment effects, we, though, also get some evidence for early anticipation effects (driven by specific scientific fields such as Life Sciences and Biomedicine). These results point to the fact that macroeconomic developments can hardly be seen as strictly exogenous but inherently reflect long-run trends. This is particularly relevant for scientific knowledge production based on perennial research projects and stable co-author relationships. Importantly, however, even in the presence of underlying long-run

trends, we find statistical evidence for a structural break in the data after the start of the Ukraine crisis and that the begin of the sanction period exacerbated the negative development of EU-Russia knowledge flows. We also find that the negative effects grow over time.

Obviously, further research is needed to fully understand the intended and unintended effects of sanctions on the economic, social, political, and cultural cooperation of involved conflict parties. Regarding the specific EU-Russia relationship, this is a highly pressing issue since there seems to be no end in sight for sanctions as political tool. Future studies should thus investigate the expected devastating long-run effects on knowledge networks that results from the socio-political alienation between the EU and Russia following the escalating Ukraine crisis. While the lifting of the sanctions seems unlikely to happen in the near future, as a long-run scenario, it will also be important to gain a better understanding of what will happen if the sanctions are terminated (Crozet et al., 2021): will scientific collaboration return to the "pre-sanctions level" or will there be a permanent drop in the level of EU-Russia collaboration as established collaboration links have been cut and alternative networks have been built up? First signs for such diversion effects following geo-political shifts could already be seen, for instance, by the Russian 'Turn to the East' -policy after 2014 (Shida, 2020). Potential path dependencies from sanctions on knowledge flows should be investigated over longer time spans. Earlier cross-county evidence provided by Afesorgbor and Mahadevan (2016) points to more severe effects if sanctions remain active for a longer duration. Finally, future research should also go beyond the macro level evidence provided here and assess changes in the underlying science systems of involved conflict parties based on meso- and micro-level information.

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