ECONOMISTS FOR UKRAINE

WORKING PAPER SERIES

WORKING PAPER No. 48 OCTOBER 2026

RUSSIA'S SOFTWARE DEVELOPER EXODUS AFTER THE UKRAINE INVASION: EXPORT GAINS AND NETWORK INTEGRATION IN VISA-FREE DESTINATION COUNTRIES

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ABSTRACT

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JEL CLASSIFICATION: F22; F14; J61

KEYWORDS: Skilled migration; ICT services; Synthetic control; Sanctions; Software developers; Russia

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Abstract

After the invasion of Ukraine, Russia's exports in ICT services, one of few internationally competitive sectors not based on natural resources, fell from US$7.23 billion in 2021 to US$2.70 billion in 2025, while those of Georgia, Armenia and Montenegro together rose from US$0.72 billion to US$2.99 billion. Relying on synthetic controls, we provide evidence that the gains of these countries were linked to a mass exodus of Russian IT developers, who were able to enter these countries visa-free and stay for extended periods. Our evidence shows that in Georgia, Armenia and Montenegro, ICT exports exceeded their synthetic counterfactuals by about US$3.3 billion in 2022-2024. Additional analyses on a smaller set of control countries show evidence that this effect persists in 2025. Moreover, about 42,000 additional developer accounts appeared on GitHub, an increase of 40 % over the three countries' 2021 stock. Finally, we provide evidence that developers also transferred their international networks: collaboration per developer with partners outside Russia and Belarus increased nearly fourfold, while the number of partner economies rose by 19. Most of the new ties lead to Europe and North America rather than to Russia. The effects persisted completely or at least partially until the end of our observation period.

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1 Introduction

The invasion of Ukraine in February 2022 severely affected one of Russia's few internationally competitive industries outside the natural-resource sector: information technology and software development. Russia's ICT service exports fell by 63 % between 2021 and 2025, from US$7.23 billion to US$2.70 billion (World Bank 2026). While the sanctions plausibly caused much of this decline (Crozet and Hinz 2020; Morgan, Syropoulos and Yotov 2023; Egorov, Korovkin, Makarin and Nigmatulina 2025), the precise mechanisms remain unclear. It is for example unclear to what degree the business opportunities were relocated to other countries and what the driving mechanism was.

Besides business opportunities taken by competitors, attempts to evade sanctions by rerouting invoices through letterbox or affiliated companies located in non-sanctioning countries are well documented (Fisman, Marcolongo and Wu 2025; Yalçin et al. 2025; Chupilkin, Javorcik and Plekhanov 2026; Scheckenhofer, Teti and Wanner 2025). Moreover, there are substantial indications of a mass exodus of Russian IT developers (Anastasiadou, Volgin and Leasure 2024; Kamalov, Nugumanova and Sergeeva 2025), where even industry associations and the Russian government reported on tens of thousands of departing IT workers within weeks of the invasion and about 100,000 by the end of 2022. Unlike the creation of affiliated companies in third countries, an exodus of developers can create a severe threat to the competitiveness of the Russian ICT sector. On the mirror-side, it can offer a windfall to the destination countries (cf. Waldinger 2016; Prato 2025). Despite some small-scale exploratory evidence by Wachs (2022) tracing the routes and destinations of the exodus, except for a descriptive account in Livny, Lim and Mamatova (2024), there is no systematic evidence on the economic consequences of the developers' arrival in these countries nor on how permanent these consequences were.

Against this backdrop, this paper has three objectives. First, focusing on Georgia, Montenegro and Armenia (GMA group) as the top-receiver countries identified by Wachs (2022), we use synthetic-control designs to test whether these countries experienced a rise in ICT exports that can be causally linked to the Ukraine invasion. Second, we test whether developer emigration played a role. If developer relocation contributed to the export gains, the receiving countries should exhibit not only higher ICT service exports but also increased software activity. Third, we examine whether relocated developers also transferred their international professional

networks. This distinction matters because additional developers expand a destination country's productive capacity, whereas their cross-border ties may also improve access to foreign knowledge, collaborators, clients, and markets. Such connections can embed the receiving software sector in international production networks and may therefore generate effects that persist beyond the developers' immediate output. Evidence of stronger and more geographically diversified collaboration would thus indicate that relocation changed not only where software was produced, but also the destination countries' position within the international division of software production.

We combine national accounts and balance-of-payments data from the World Bank, Eurostat and national statistical offices with the GitHub Innovation Graph, which assigns git pushes, repositories, organisations and developer accounts to countries by IP address and records cross-border collaboration. Based on Wachs' (2022) exploratory analysis, we distinguishing a group of countries with presumably high inflows, notably Georgia, Montenegro and Armenia (GMA Group) from a group of countries with lower inflows Kazakhstan, Serbia, Uzbekistan and Kyrgyzstan (KSUK Group). For each group estimate the effects of the Ukraine invasion on exports, software activity and developer networks with a synthetic-control design (Abadie, Diamond and Hainmueller 2010; Abadie 2021).

Our estimates show substantial export windfalls in the GMA group, where exports rose by a combined 128 % relative to their synthetic controls over 2022 to 2024. The three countries gained about US$3.3 billion in current dollars, equal to 31 % of Russia's shortfall against its 2021 export level and, valued at 2021 prices, to 7.6 % of their combined 2021 GDP. Software activity rose by 106 % in git pushes, 60 % in organisations and 74 % in repositories, and the three countries gained about 42,000 developer accounts. Collaboration per developer account with partners other than Russia and Belarus rose almost fourfold. The new ties led mainly to Europe and North America, and by 2025 connections to Russia had fallen below their pre-war level. As concerns permanence of the effects, all measures rose sharply in 2022. Git pushes fell back to about half of their peak by 2025, while the number of new organisations, export volume and collaboration stayed close to their peak levels until the end of the observation period in 2025. Interestingly, in the KSUK group, we observe similar-sized increases in exports, which were however not accompanied by proportionate increases in software activities. We provide descriptive and institutional evidence that in these countries, the rise in export volume was probably driven the activities aimed at exploiting leak sanctions rather than by the physical relocation of software development.

The paper contributes to three strands in the literature. First, it contributes a recent account of how political shocks redistribute skilled workers and knowledge across countries (Borjas and Doran 2012; Moser, Voena and Waldinger 2014; Waldinger 2016; Ganguli and Waldinger 2024). Second, it extends research on the consequences of high-skilled migration for origin and destination countries (Docquier and Rapoport 2012; Kerr, Kerr, Özden and Parsons 2016; Prato 2025; Batista et al. 2025) to digitally delivered services, for which production can relocate with workers and output is recorded as service exports. Third, it connects research on how migrants affect host countries' trade patterns and comparative advantage (Gould 1994; Rauch and Trindade 2002; Bahar and Rapoport 2018; Parsons and Vézina 2018) with evidence on the rerouting of trade with Russia through third countries following the imposition of sanctions (Chupilkin, Javorcik and Plekhanov 2026). The results also inform innovation policies that seek to attract mobile software talent and research policy in a period of sanctions (Section 6.1).

2 Related literature and the background of the case

2.1 Skilled migration, human capital, and networks

A substantial literature examines how political shocks induce skilled emigration and thereby affect knowledge production in origin and destination countries. A prominent case is the dismissal of Jewish and politically persecuted scholars from German universities after 1933. Departments that lost professors trained fewer successful doctoral students (Waldinger 2010), and the loss of human capital, unlike that of physical capital, persisted in the long run (Waldinger 2016). Destination countries benefited correspondingly: US patenting increased in the fields of chemistry in which the emigrants had worked (Moser, Voena and Waldinger 2014). More generally, skilled immigration raises innovation in host economies (Hunt and Gauthier-Loiselle 2010; Kerr, Kerr, Özden and Parsons 2016).

The dissolution of the Soviet Union provides a second episode. Soviet mathematicians who moved to the United States reduced the output of US mathematicians in the same fields (Borjas and Doran 2012), but Soviet scientists who relocated also raised US citations to their earlier work (Ganguli 2015). Skilled migration can therefore change both the location of productive activity and the geography of knowledge diffusion.

A related literature emphasises the persistence of migrants' professional networks. Inventors who relocate continue to be cited disproportionately by former colleagues (Agrawal,

Cockburn and McHale 2006). Moreover, ethnic scientific communities in the United States speed the diffusion of technology to their countries of origin (Kerr 2008). Such links, together with remittances, return migration and stronger incentives to acquire education, may offset part of the losses of the origin countries (Docquier and Rapoport 2012; Fackler, Giesing and Laurentsyeva 2020; Batista et al. 2025), although diaspora knowledge flows do not appear to compensate for losses completely (Agrawal, Kapur, McHale and Oettl 2011). These findings identify two consequences of skilled migration that are central to the present study: the relocation of productive capacity and the persistence of cross-border knowledge networks.

The post-2022 relocation of Russian software developers provides a contemporary setting in which both consequences can be examined jointly, but it differs from the two preceding historical episodes some ways. The invasion, international sanctions, and, after September 2022, military mobilisation reduced the expected returns to remaining in Russia, particularly for developers and firms dependent on foreign clients, payment systems, and collaborators. Unlike the Jewish scientists in Nazi Germany, developers were not pushed out, nor was a relocation barrier removed as in the case of the collapse of the Soviet Union. In addition, software firms also possessed an alternative unavailable in the two other historical cases. Notably, they could relocate contracts and legal entities without necessarily relocating workers. The observed rise in ICT exports in nearby countries may therefore reflect either a transfer of human capital and networks or the administrative rerouting of business activity. The next subsection therefore examines how sanctions and mobility constraints created two distinct adjustment channels: the relocation of contracts and the physical relocation of developers.

2.2 The invasion, sanctions, and two channels of relocation

Russia invaded Ukraine on 24 February 2022, eight years after annexing Crimea. The conflict became a prolonged war of attrition, and in September 2022 Russia declared the annexation of four Ukrainian regions and announced a partial mobilisation. At home, a law of March 2022 criminalised “false information” about the armed forces (Federal Law No. 32-FZ of 4 March 2022), while Western governments introduced successive rounds of sanctions. By October 2025 the European Union alone had adopted nineteen packages (Council of the European Union 2025).

The first set of measures disrupted payment and contracting channels. In March 2022, the European Union excluded seven Russian banks from SWIFT (Council Regulation (EU)

2022/345), while Visa and Mastercard suspended their Russian operations. From 6 March 2022, cards issued in Russia no longer functioned abroad (1TV 2022). A Russian software firm could therefore continue to supply code to a client in Berlin or San Francisco but faced increasing difficulties in receiving payment. Western clients also withdrew from projects with suppliers in Russia, and Western software vendors such as Microsoft, Oracle and SAP suspended their business in the Russian market (CNBC 2022; Al Jazeera 2022b). Exit was nevertheless far from complete. Evenett and Pisani (2023) estimate that only 5 to 13 % of Western firms with Russian subsidiaries had divested them during the first nine months of the war. Subsequent sanctions targeted IT services more directly by restricting their provision to Russia. From October 2022, the EU prohibited IT consultancy services to the Russian government and to legal persons established in Russia. From December 2023, the prohibition also covered enterprise-management and design software, although existing contracts could continue until 20 March 2024 (Council Regulations 2022/1904 and 2023/2878). The United States prohibited IT consultancy, design, support, and cloud services to Russia from 12 September 2024 (OFAC 2024).

Because these restrictions generally attached either to a firm’s place of registration or to the location of its bank rather than to the person performing the work, relocation offered a response in two forms. First, a firm could establish an affiliate in a neighbouring country that did not fully apply the sanctions, invoice Western clients through that entity and receive payment through a local bank while its developers remained in Russia. Second, on an individual level, developers could move to such a country, open bank accounts and continue working for the same clients or the same Russian employer. Both channels raise the destination’s recorded ICT exports, but only the second transfers human capital and professional networks. For trade in goods, Chupilkin, Javorcik and Plekhanov (2026) estimate that trade routed through non-sanctioning countries offset about one-third of the decline in European exports to Russia. For services, a locally registered company and a functioning bank account may suffice.

At the same time, mobility constraints changed the relative accessibility of potential destinations. The EU banned Russian aircraft from its airspace on 27 February 2022 and suspended its visa-facilitation agreement with Russia in September. On 19 September, Poland and the Baltic states closed their borders to Russian citizens holding Schengen tourist visas, and Finland followed on 30 September (Council Decision (EU) 2022/1500; Al Jazeera 2022a). The Russian government, by contrast, introduced measures intended to retain IT

workers. A decree of 2 March 2022 granted accredited IT firms a zero profit-tax rate until 2024 and offered their employees subsidised mortgages and, up to age 27, deferment from military service (Presidential Decree No. 83 of 2 March 2022). The value of these incentives declined, nonetheless, sharply after the announcement of partial mobilisation on 21 September 2022, which increased the personal cost of remaining in Russia.

Consistent with this sequence, developers left Russia in two principal waves, immediately after the invasion and after the mobilisation. In March 2022 the Russian Association for Electronic Communications estimated that 50,000 to 70,000 IT workers had already departed (Datacenter Dynamics 2022). In December the Minister of Digital Development estimated that about 100,000 had left during 2022, or 10 % of the sector's workforce, and reported that 80 % of them continued to work for Russian companies (Interfax 2022).

These figures also show why the two relocation channels cannot be treated as mutually exclusive. A developer who moves to Yerevan, Armenia but retains a Moscow employer transfers the location of production while leaving the client relationship, and potentially part of the revenue, with the Russian firm. Russia nevertheless loses the worker’s physical presence, personal income-tax base, and some influence over subsequent location decisions. Moreover, emigrants were not a random subset of Russian developers. Wachs (2022) reports that 43.0 % of those who left had international collaborative ties, compared with 24.3 % of those who remained, and that emigrants accounted for 20 % of Russia’s pre-invasion cross-border collaborative ties. Survey evidence further indicates that most emigrants do not intend to return in the absence of political change in Russia (Kamalov, Nugumanova and Sergeeva 2025). The next subsection therefore turns from the incentives to leave to the geography of relocation, asking which destinations were accessible and why the inflows were concentrated in a small set of countries.

2.3 Destination patterns and the role of accessibility

The mobility constraints described in the preceding section shaped not only whether developers could leave Russia, but also where they could relocate. Relative to the size of receiving software sectors, the inflow was concentrated in a small number of countries. While the data source based on self-declared GitHub locations is highly incomplete, Wachs (2022, Table 3) identifies eleven economies in which arrivals from Russia and Belarus exceeded 5 % of the developers observed in 2021. The inflow was equivalent to 94 % of Georgia’s pre-existing developer base, 73 % of Montenegro’s, 60 % of Cyprus’s, and 42 % of Armenia’s.

The corresponding shares were considerably smaller in the United Arab Emirates (14 %), Kazakhstan (13 %), Serbia and Uzbekistan (8 % each), Kyrgyzstan (7 %), and Lithuania and Estonia (6 % each). The numbers are useful but remain indicative. In absolute terms, Wachs (2022) identified only a few thousand developers, whereas the reported exodus of IT developers was about a hundred times larger, an order of magnitude we corroborate with IP-based GitHub measures instead of Wachs' self-reported locations.

Visa-free destinations nevertheless differed substantially in the duration of permitted stays and the ease with which residence could be extended. Georgia admitted Russian citizens for 365 days, with a brief departure restarting the permitted period (Civil.ge 2015). It was accessible by land through the Upper Lars crossing and by air via Istanbul or Yerevan. In October 2022, the Georgian Ministry of Internal Affairs reported that 112,733 Russian citizens who had entered between January and September remained in the country (Radio Svoboda 2022). Russians also registered approximately 16,000 companies in Georgia during the year after the invasion (Kyiv Independent 2024). Armenia permitted stays of up to 180 days per entry and, since 2017, allowed Russian citizens to enter using internal passports (Armenpress 2017). This provision was particularly relevant for men without passports for international travel. A trip to Georgia and back restarted the 180-day period, while registration under a 1997 bilateral treaty permitted an indefinite stay (Meduza 2026b). Direct flights between Yerevan and Moscow also continued throughout the period.

The economic consequences of these inflows have so far been documented only descriptively. Livny, Lim and Mamatova (2024) describe a boom in banking, real estate and ICT across the Caucasus and Central Asia, including a near doubling of ICT employment in Armenia in 2022, but note that the causal contribution of the migrants cannot be estimated with any precision from aggregate data. Our synthetic-control estimates address this gap for exports, software activity and collaboration.

Montenegro and Serbia initially permitted shorter stays of 30 days, but repeated re-entry made longer residence possible. In Montenegro, a brief trip to Bosnia and Herzegovina or Serbia restarted the 30-day period. Until 2023, Russian citizens could also obtain residence by registering a company that paid its owner a monthly salary of €450. Subsequent rules required genuine business activity and three employees, including one Montenegrin citizen (Russian Life 2025). Montenegro differs from the other GMA countries because it adopted EU sanctions in full on 2 March 2022 (N1 2022). It therefore offered a location from which Russian developers could live and work, but not an obvious base for circumventing sanctions

through local billing. Its statistical office records approximately 12,000 Russian residents, and, as part of preparations for EU membership, Montenegro plans to introduce visa requirements for Russian citizens in November 2026 (Meduza 2026a). Serbia's 2009 agreement with Russia likewise limited each stay to 30 days but imposed no ceiling on cumulative days, allowing repeated re-entry to extend residence indefinitely. Serbia did not join the sanctions, and Air Serbia maintained flights to Moscow and St Petersburg. Approximately 30,000 Russians obtained temporary residence, while Russian citizens established 6,976 companies after the invasion, with IT as the largest sector among them (Khan 2023).

Accessibility also characterised several destinations in Central Asia, although large population movements did not necessarily translate into large developer inflows. Kazakhstan and Kyrgyzstan belong with Russia to the Eurasian Economic Union. Russian citizens could initially remain in Kazakhstan for 90 days and restart the period by travelling to Bishkek and returning. A rule effective from 27 January 2023 subsequently limited stays to 90 days within any 180-day period. Approximately 406,000 Russians entered Kazakhstan after the announcement of mobilisation (Meduza 2023), but Wachs's estimates indicate that relatively few were developers (Wachs 2022, Table 3). Cyprus presents a different case. As an EU member, it required a visa, but it had long served as the legal domicile of many Russian firms (Ledyaeva et al. 2015). Its high relative developer inflow may therefore reflect pre-existing corporate and professional ties rather than ease of entry alone.

In summary, visa-free entry or an established institutional connection thus determined the set of feasible destinations.

2.4 Selection of the study destinations

Building on Section 2.3, we first delimit the set of study destinations on historical-geographic and institutional grounds. Out of Wachs' (2022) list, we consider former Soviet republics and former Warsaw Pact countries or closely affiliated states. We exclude members of the EU and that appear among the destinations identified by Wachs, because these adopted the EU sanctions. This yields seven countries: Georgia, Montenegro, Armenia, Kazakhstan, Serbia, Uzbekistan, and Kyrgyzstan, excluding Cyprus, Lithuania, and Estonia as EU members and United Arab Emirates, the latter because it falls outside this regional criterion and, in addition, reports ICT service exports only from 2023. In a second step, subdivide the remaining countries developer inflows relative to each country's pre-existing developer base reported in

Wachs (2022, Table 3; Section 2.3). The ranking contains a pronounced break between Armenia, where the inflow was equivalent to 42 % of the 2021 developer base, and Kazakhstan, where it was 13 %. Georgia, Montenegro, and Armenia lie above this break and form the GMA group, our primary group of interest. Kazakhstan, Serbia, Uzbekistan, and Kyrgyzstan lie below it and form the KSUK group, which provides a secondary comparison among otherwise eligible destinations.

3 Data

Our study builds completely on public sources. We draw the ICT service exports per capita (used on logarithms) in constant 2021 US dollars from the World Development Indicators (BX.GSR.CCIS.CD) deflated with the US consumer price index. Because the Georgian lari and the Armenian dram appreciated in 2022, we also construct a local-currency measure deflated by each country's GDP deflator. The export series begin in 2005, in 2007 for Montenegro and Serbia, and in 2013 for Uzbekistan's local-currency series. The annual post-treatment period ends in 2024, because only 21 of the 52 donors report ICT service exports for 2025 in the WDI release of 13 July 2026. Section 5.5 extends the export estimates to 2025 with these donors.

We link the export measures to quarterly indicators of software production from version 1.0.10 of the GitHub Innovation Graph, available from 2020Q1 onward. The database assigns public activity to economies on the basis of developers' IP addresses. We analyse the number of git pushes, organisations, repositories and developer accounts, all per capita and in logarithms. The GitHub measures capture only public activity (GitHub 2026). Contributions to private repositories and activity on other platforms are not observed. Moreover, developer accounts should not be interpreted as a census of professional developers. GitHub reported more than 100 million accounts in 2023 (GitHub 2023), whereas SlashData (2025) estimated the global population of professional developers at 36.5 million in 2025. We therefore interpret the GitHub outcomes as indicators of observable software activity rather than measures of total software output. This is however not crucial for identification, which only requires that, after 2022, the software activity observed did not change differentially between the destination and donor countries. A time-invariant difference in this share is absorbed by the log-gap design.

The Innovation Graph also reports, for each pair of economies and quarter, the git pushes and pull requests made by developers in one economy to repositories owned in the other.

Aggregating both directions, we construct two measures. Collaboration intensity is the logarithm of the collaboration weight with all partners other than Russia and Belarus, divided by the number of developer accounts. Collaboration breadth is the number of partner economies with a reported link. Because GitHub reports bilateral links only when at least 100 developers contribute, growth of the developer base can lift further pairs above the threshold, which matters more for breadth than for intensity. Repositories are assigned to the modal location of their members, so the measures capture reported cross-border links rather than all collaboration (GitHub 2026).

To measure developer relocation, we use the inflow shares reported by Wachs (2022, Table 3), based on changes in developers' self-reported GitHub profile locations during 2022. Both sources describe GitHub users, but Wachs locates them by self-reported profile locations and the Innovation Graph by IP address, so agreement between the two does not arise mechanically. Because Wachs's underlying counts are small, we use the inflow shares only to rank destinations, not as head counts.

Table 1 summarises the seven destinations in 2021. The GMA countries were small, with an average population of 2.4 million against 16.9 million in the KSUK group. Their ICT service exports averaged only US$240 million but had grown by 18 % a year between 2015 and 2021, compared with 0.7 % in the KSUK group and 3.3 % for the median donor. Their developer communities were already large relative to population, with 13.9 GitHub accounts per 1,000 inhabitants, against 7.9 in the KSUK group, 13.4 in Russia and 4.2 for the median donor. Arrivals averaged 70 % of the 2021 developer population, compared with 9 % in the KSUK group (Wachs 2022). Serbia is an exception within the KSUK group, with by far the largest ICT export sector (US$2.2 billion) and the highest developer density (20 accounts per 1,000 inhabitants).

Table 1. Descriptive statistics, 2021

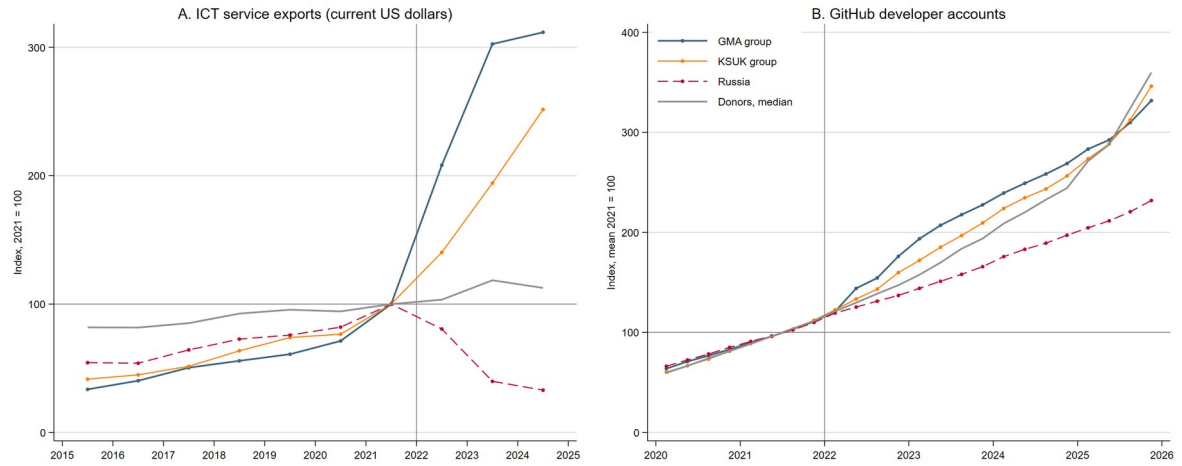
	Population (mn)	GDP per capita (US dollars)	ICT exports (million US dollars)	ICT exports (% of GDP)	ICT export growth 2015–21 (% p.a.)	Developer accounts	Accounts per 1,000 inhabitants	Partner economies	Inflow (% of 2021 developers)
Georgia	3.71	5,175	216	1.15	26.1	48,325	13.0	11.8	94
Montenegro	0.63	7,198	121	2.08	10.1	7,830	12.5	5.5	73
Armenia	2.96	4,265	382	2.76	17.9	47,354	16.0	10.3	42
GMA group (mean)	2.43	5,546	240	1.99	18.0	34,503	13.9	9.2	70
Kazakhstan	19.74	10,873	192	0.10	4.9	115,894	5.9	8.0	13
Serbia	6.83	7,466	2,191	3.31	19.6	136,377	20.0	29.3	8
Uzbekistan	34.24	3,952	176	0.22	−2.7	60,779	1.8	6.8	8
Kyrgyzstan	6.85	1,133	14	0.15	−19.0	27,360	4.0	4.3	7
KSUK group (mean)	16.92	5,856	643	0.94	0.7	85,102	7.9	12.1	9
Russia	144.75	10,231	7,232	0.40	10.2	1,936,722	13.4	76.8	

	Population (mn)	GDP per capita (US dollars)	ICT exports (million US dollars)	ICT exports (% of GDP)	ICT export growth 2015–21 (% p.a.)	Developer accounts	Accounts per 1,000 inhabitants	Partner economies	Inflow (% of 2021 developers)
Donors, median (n = 52)	5.85	3,983	100	0.29	3.3	23,541	4.2	4.3	

Note: Values for 2021 unless stated otherwise. GDP per capita in constant US dollars (WDI NY.GDP.PCAP.KD), ICT service exports in current US dollars (WDI BX.GSR.CCIS.CD). Growth: mean annual log growth 2015–2021. Developer accounts (GitHub Innovation Graph) and partner economies (economies with a reported collaboration link): means of 2021Q1–Q4. Inflow: Russian and Belarusian developers who had arrived by November 2022 in % of developers observed in 2021 (Wachs 2022, Table 3). Group rows: unweighted means. Donors: medians of the donor pool of the annual export models. Further columns: Online Appendix, Table A1.

Figure 1 presents the unadjusted series. ICT service exports of the GMA group rose from US$0.72 billion in 2021 to US$2.24 billion in 2024 and those of the KSUK group from US$2.57 billion to US$6.47 billion, while Russia's fell from US$7.23 billion to US$2.39 billion (Table 1 and Online Appendix, Table A1). Developer accounts grew at similar rates in all groups, including Russia, until 2022 and faster in both destination groups thereafter. The series also show the need for a counterfactual: GitHub activity rose across countries, and exports of the GMA group were already growing rapidly before 2022.

Figure 1. Unadjusted trajectories of ICT service exports and GitHub developer accounts



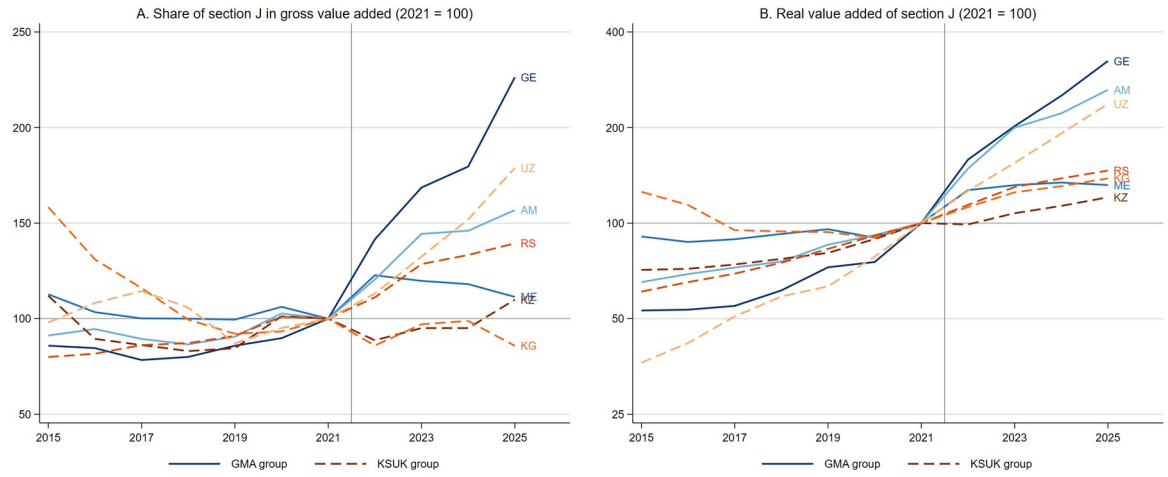
Note: ICT service exports in current US dollars, 2021 = 100. Developer accounts, 2021 quarterly mean = 100. Group totals, Russia and the donor median.

We use ICT service exports as the principal measure of the economic gains associated with relocation. They capture cross-border sales generated by software activity and are reported under harmonised balance-of-payments standards for most countries from 2005 onward, providing consistent coverage across the donor pool. We complement this measure with value added in information and communication (NACE Rev. 2, section J), which captures domestic production but is available from national statistical offices only for the seven destination countries and over shorter periods. ICT service exports therefore provide the basis for the

synthetic-control analysis, while the value-added data offer additional descriptive evidence on developments in domestic production.

For the seven destinations, we collected value added in section J from the national statistical offices and Eurostat (Online Appendix, Table A2). In Georgia and Armenia, real value added of the sector grew by 34 % and 27 % a year over 2022 to 2025, against 13 % and 8 % over 2017 to 2021, and much faster than the rest of their economies (Figure 2). Its share of total value added rose from 3.5 % to 8.0 % in Georgia and from 4.2 % to 6.5 % in Armenia. In Montenegro the sector grew in 2022 and then stalled. In the KSUK group, growth of the sector relative to the whole economy accelerated by about one percentage point a year after 2022, against eleven in the GMA group. Section J also covers telecommunications and publishing, but the figures indicate that where developers arrived, exports moved together with domestic production. Where few developers arrived, exports rose without such a counterpart, a pattern we return to in Section 5.4.

Figure 2. Value added in information and communication (NACE Rev. 2 section J), destination economies, 2015–2025



Note: A: share of section J in total gross value added. B: real value added of section J. Both 2021 = 100. Sources: national statistical offices and Eurostat.

4 Design

We use the synthetic control method (SCM) to estimate how each destination would have developed after the invasion in the absence of the shock. SCM constructs this counterfactual as a weighted average of countries that were not exposed in the same way. It is well suited to our setting because the invasion occurred at a common, clearly defined date, the number of

strongly affected destinations is small, and no single comparison country provides an obvious benchmark for their pre-2022 trajectories. Let i denote a destination and $j = 1, \ldots, J$ the donor countries. The variable Y_{it} is the observed outcome for destination i in period t, such as log ICT service exports per capita. Periods $t \leq T_0$ form the pre-invasion period, while periods $t > T_0$ form the post-invasion period. After 2022, we observe Y_{it} but not Y_{it}^N, the outcome that destination i would have realised without the invasion. The period-specific effect is therefore

SCM approximates the unobserved counterfactual Y_{it}^N by a weighted average of the donor outcomes (Abadie, Diamond and Hainmueller 2010),

Here, is the weight assigned to donor . Each weight is non-negative and sum to one. They are chosen so that the weighted donor combination matches the destination before the invasion. Let denote the vector of pre-invasion predictors for the destination and the matrix containing the same predictors for the donor countries. The vector of donor weights solves

The diagonal matrix assigns relative importance to the predictors when measuring the distance between the destination and a candidate synthetic control. Under nested optimisation, is selected so that the resulting synthetic control fits the destination's outcome as closely as possible in the pre-invasion period. More precisely, it minimises the pre-period mean squared prediction error , where is the final pre-invasion period. The restrictions that the donor weights are non-negative and sum to one imply that the synthetic control is a convex combination of observed donor countries rather than an extrapolation beyond them.

For each destination, we summarise the estimated effect by the average post-invasion gap,

In this expression, the summation covers the post-invasion periods . The result is measured in log points and is converted into a percentage as . For a group containing destinations, the pooled effect is the simple average of the destination-specific effects. Since the outcomes enter in logarithms, we recover effects in levels separately for each period. If denotes the observed level of exports or some measure of software activitiy, the corresponding gain is

We estimate separate synthetic-control specifications for the annual export outcomes and the quarterly GitHub outcomes, using Stata's synth command with nested optimisation of the predictor-weighting matrix V. The donor pool excludes economies that were exposed to the same shock: all successor states of the Soviet Union, including Russia, Belarus and Ukraine, other known destinations of Russian emigrants and firms (Turkey, Israel, the United Arab Emirates, Cyprus, Serbia and Montenegro), and the members of the EU and EFTA, which received substantial numbers of Ukrainian refugees in 2022. We further restrict the donors to economies with between 0.5 and 30 million inhabitants in 2021, which excludes microstates and the largest economies. A donor must report the relevant outcome without gaps, which leaves 52 countries for ICT service exports. The pre-period begins in 2005 (2007 for Montenegro and Serbia, 2013 for Uzbekistan's local-currency series) and ends in 2021. For the annual exports, the predictors are the outcome means for 2005–2009, 2010–2014, 2015–2019 and 2020–2021 and the 2015–2021 means of log GDP per capita, internet use and the services share of GDP (WDI NV.SRV.TOTL.ZS). For the quarterly GitHub outcomes, the pre-period is 2020Q1–2021Q4 and the predictors are one lag of the outcome per quarter. These donor pools contain between 59 and 83 countries, and 42 for the collaboration measures, which require complete bilateral series. We treat 2022Q1 as a transition quarter and exclude it from both the fit and the effect. The post-period is 2022–2024 for exports and 2022Q2–2025Q4 for the GitHub outcomes. Because the quarterly pre-period is short and falls within the pandemic, Section 5.5 checks that the quarterly results do not depend on a close fit over these eight quarters. When nested optimisation did not converge, we used regression-based predictor weights, in 5 of 259 annual and 4 of 322 quarterly fits.

Inference uses in-space placebos, i.e. each donor in turn is treated as if it had been exposed. The main statistic is the pooled effect of the GMA group, the mean of their gaps, with the p-value from the permutation scheme of Cavallo et al. (2013). Specifically, we draw one placebo per destination 10,000 times and count how often the mean of the drawn placebo gaps is at least as large in absolute value as the observed mean. On the annual data we use only placebos whose pre-treatment MSPE is at most five times that of the destination as suggested by Abadie et al. (2010). Section 5.5 reports the results under alternative filters. On the quarterly data we use all placebos. With eight pre-period quarters and one lag per quarter, synth reproduces the pre-period of the destinations almost exactly, so a threshold relative to their MSPE would select on numerical noise rather than on the quality of the fit. We note that the exact reproduction may be a result of short pre-treatment periods. We thus provide

additional robustness analyses including for example synthetic differences-in-differences to rule out potentially resulting overfitting biases.

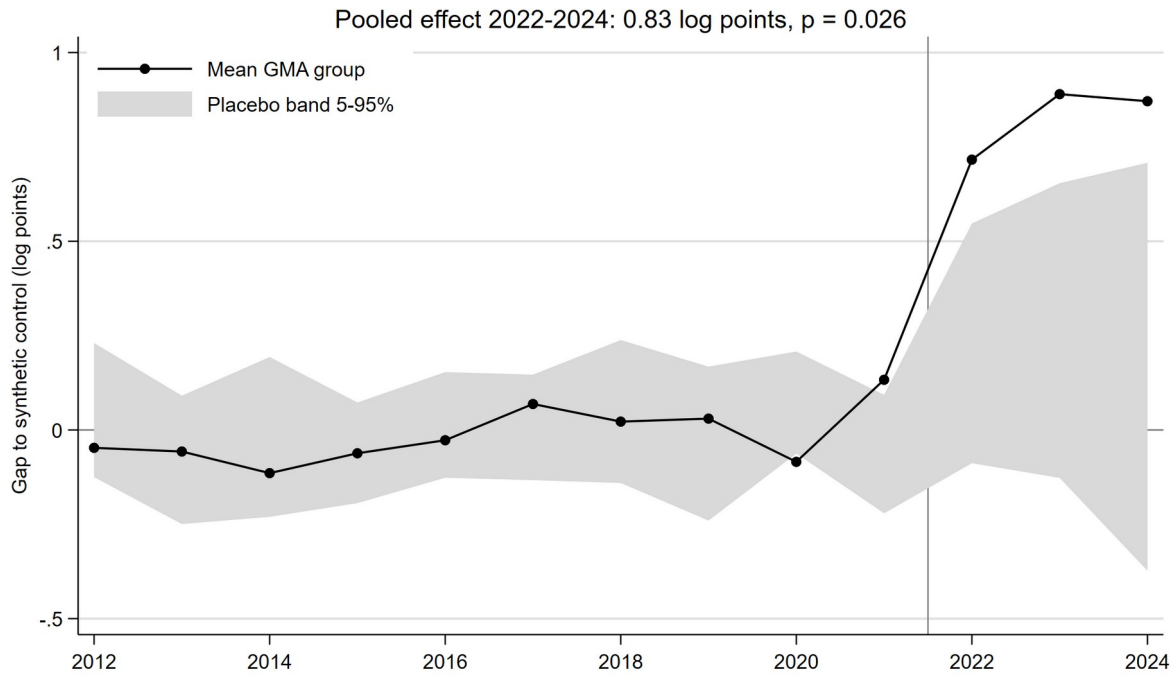
To support our a priori decision to separate the GMA from the KSUK group, we validate Wachs's inflows as the measure of where developers went and compute Spearman's rank correlation between his inflow shares and our effects across the seven destinations and derive its p-value exactly from all 5,040 orderings.

5 Results

5.1 ICT service exports

Applying the synthetic-control design developed in Section 4, we first estimate the effect of the invasion on the principal economic outcome: ICT service exports. Across the GMA group, exports were on average 0.83 log points, or 128 %, above their synthetic controls during 2022–2024 (Figure 3). The pooled p-value is 0.026 with the filter (Section 4). The corresponding local-currency estimate is 0.89 log points (p = 0.008 with the filter and 0.11 without it), indicating that the dollar-denominated effect is not attributable to the appreciation of the Georgian lari and Armenian dram.

Figure 3. Pooled synth gap in ICT service exports per capita, GMA group



Note: Shaded area: 5 to 95 % placebo band.

Figure 3 presents the pooled gap and the corresponding placebo band. The gap remains within the band from 2012 through 2020. In 2021, it reaches 0.13 log points, at the upper boundary of the band. From 2022 through 2024, it exceeds the band in every year, with gaps of 0.72, 0.89, and 0.87 log points, respectively. Additional analyses based on a reduce donor pool because of missing data show that the effects remain significant and at a stable level even in 2025 (see Section 5.5).

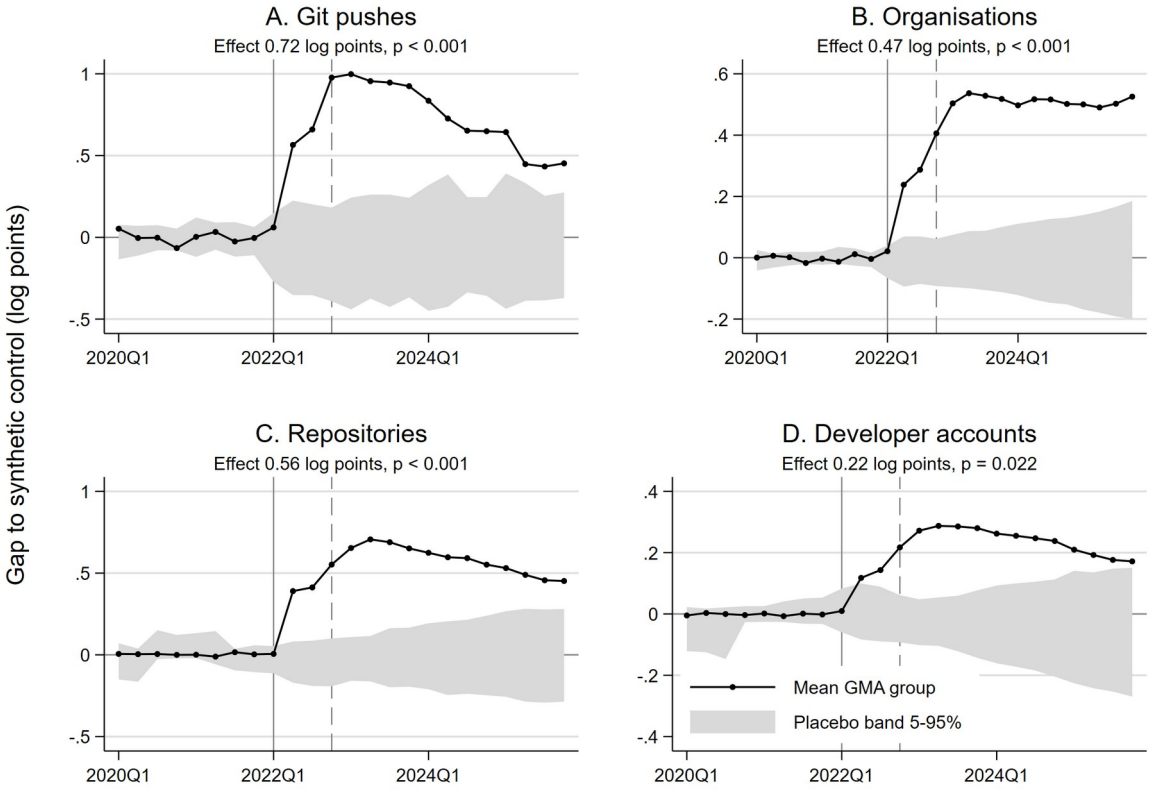
Equation (5) converts these log-point effects into economically meaningful levels. Over 2022–2024, the estimated gains amount to approximately US$ 1.8 billion for Georgia, US$ 1.3 billion for Armenia and US$ 0.25 billion for Montenegro in current dollars (Table A4). Valued at 2021 prices, they equal 8.3 % of 2021 GDP in Georgia and in Armenia and 3.8 % in Montenegro. The combined gain is approximately US$ 3.3 billion, with a placebo band of US$0.20–3.7 billion. For descriptive context, this combined gain corresponds to 31 % of the US$ 10.6 billion decline in Russia's ICT service exports relative to its 2021 level over the same period, and to 27 % of the US$ 12.4 billion shortfall relative to its 2015–2021 trend (Table A4). These comparisons do not imply that the gains in the three destinations originated entirely from activity previously recorded in Russia. National accounts show that value added in the information and communication sector of Georgia and Armenia rose together with these exports (Section 3).

5.2 Software activity

The export estimates establish an economic gain but do not identify whether it reflects the physical relocation of developers or only the relocation of contracts and billing. We therefore turn to the GitHub outcomes, which measure software production and the size of the developer base. Relative to their synthetic controls, git pushes per capita in the GMA group were 0.72 log points, or 106 %, higher over 2022Q2–2025Q4 ($p < 0.001$, Figure 4 and Table 2). Organisations increased by 0.47 log points and repositories by 0.56 log points (both $p < 0.001$). Developer accounts, which include inactive accounts and therefore adjust more slowly, increased by 0.22 log points ($p = 0.022$). In levels, the three countries gained approximately 42,000 developer accounts on average over 2022Q2–2024Q4, with a placebo band of 27,000–62,000 (Table A4). In Georgia alone, the estimated gain corresponds to 62 % of the country's 2021 stock. Set against the export gain of Section 5.1, the additional accounts correspond to about US$26,000 of exports per account and year. This is close to the annual take-home pay of a mid-level developer in Russia in 2022, about 150,000 roubles a month or US$26,000 a year at the average exchange rate (Habr Career 2023; World Bank 2026), so the

export gain is of a size that the observed inflow could generate. The ratio is rough, because accounts include inactive users and export revenue covers more than wages.

Figure 4. Pooled synth gaps in GitHub activity per capita, GMA group



Note: Git pushes, organisations, repositories and developer accounts. Shaded areas: 5 to 95 % placebo bands.

Figure 4 shows a common temporal pattern across the four outcomes. The gaps are approximately flat during the eight pre-treatment quarters and increase sharply in 2022Q2. The gap in git pushes reaches about 1.0 log point at the end of 2022, following the September mobilisation, and declines to about 0.45 by 2025, while remaining above the placebo band. Repositories and developer accounts exhibit similar attenuation, with their gaps declining from about 0.7 to 0.45 and from about 0.29 to 0.17, respectively. Organisations follow a different trajectory: their gap rises to about 0.54 log points by mid-2023 and remains between 0.49 and 0.53 through the end of 2025. The decline in pushes per capita may indicate that some developers returned or moved onward, or that the activity of those who remained shifted from establishing to maintaining projects. The data do not identify how many developers returned. They do show, however, that the number of GitHub organisations, the firms and groups within which developers work, did not contract.

To assess whether the post-2022 increase reflects an earlier break rather than the invasion, we conduct an in-time placebo with a fictitious treatment in 2021Q1, fitted on 2020 alone. The resulting 2021 push gaps range from −0.07 to 0.15 log points across the three countries, with p-values of at least 0.43 (Table A10). Although the test has limited power with only four pre-treatment quarters, it provides no evidence of an earlier break.

The export and activity gaps also move together. Both emerge in 2022 and are of similar size over 2022–2024 (Figures 3 and 4). Across the 15 country-years of the GMA group from 2020 to 2024, the annual export gap correlates with the annual mean push gap at 0.70, against 0.10 in the KSUK group (Table A5). Quarterly balance-of-payments data for Georgia and Armenia show exports and pushes rising within the same half-year, but in a different order in the two countries (Online Appendix, Table A6 and Figure A1, Granger-type tests in Table A7). The evidence establishes contemporaneous movement, not the direction of causation.

Most importantly for distinguishing developer relocation from administrative rerouting, the activity effects align with the independently measured developer inflows reported by Wachs (2022). Across the seven destinations, the rank correlation between his inflow shares and our estimated effects is 0.86 for git pushes (exact one-sided $p = 0.012$), 0.86 for organisations ($p = 0.012$), 0.61 for repositories ($p = 0.083$), and 0.68 for developer accounts ($p = 0.055$).[1] For ICT service exports, the corresponding correlation is close to zero (−0.04, $p = 0.55$). Thus, two independent location signals from the same platform, self-reported profile locations and IP addresses, identify the same destinations as receiving developers, whereas export statistics alone do not. The correspondence is in relative shares rather than absolute head counts, consistent with outcomes measured per capita and in logarithms (Online Appendix, Tables A11 and A12).

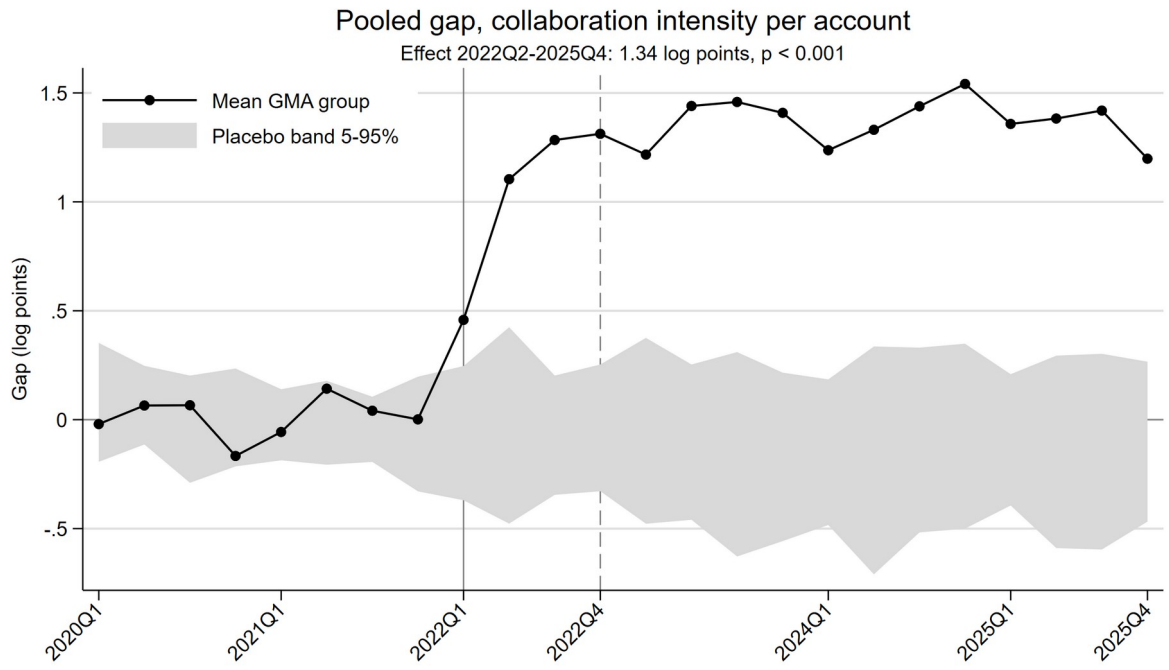
5.3 Collaboration

The preceding results show that software activity increased in the destinations that received the largest relative inflows of developers. We now examine whether relocation also transferred developers' international professional networks. Relative to their synthetic controls, collaboration per developer account with partners outside Russia and Belarus increased by 1.34 log points, or 283 %, while the number of partner economies, which also counts Russia and Belarus, increased by 19 (both $p < 0.001$, Figure 5 and Table 2). None of the 10,000 pooled placebo draws produced a mean effect as large as the observed estimate for

[1] A one sided test is chosen because two independent measures of the same underlying quantity are expected to be positively related.

either outcome. The increase in collaboration intensity was also highly consistent across the three countries, ranging from 1.32 to 1.37 log points. In each case, the estimate was the most extreme among the 42 placebos (p = 0.023, Table A13). In Georgia, for example, the average number of partner economies rose from 12 in 2021 to 41 after the invasion.

Figure 5. Pooled synth gap in collaboration intensity, GMA group



Note: Log collaboration weight with partners other than Russia and Belarus per developer account. Shaded area: 5 to 95 % placebo band.

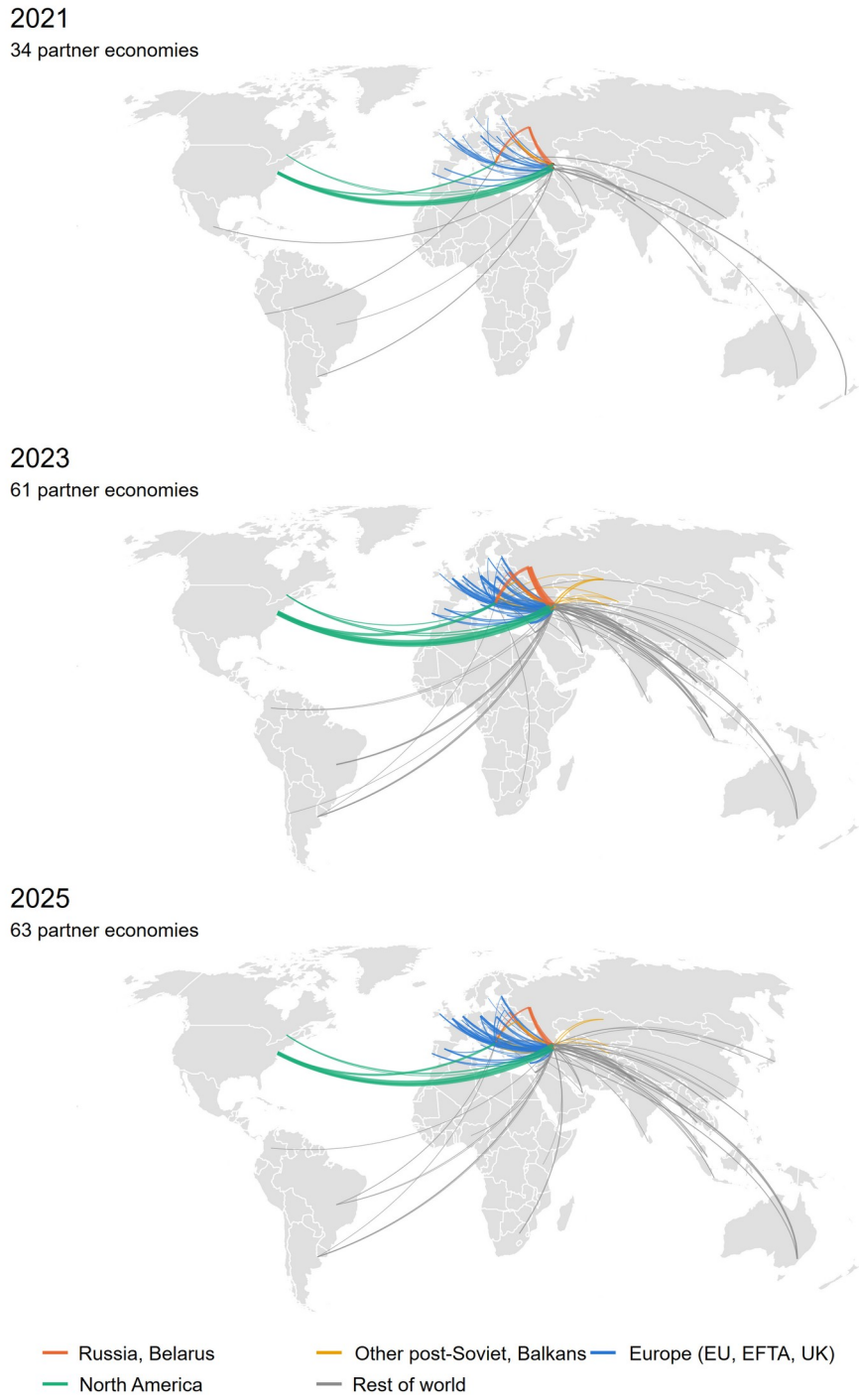
In contrast to the attenuation observed for some of measures of software activity, the collaboration effect persisted. After rising sharply in 2022, the collaboration-intensity gap remained between 1.2 and 1.5 log points throughout the following three years (Figure 5). Its trajectory therefore more closely resembles the persistent gap in organisations than the partially attenuating gap in git pushes.

Two features affect the interpretation of the estimated magnitude. First, because GitHub reports bilateral links only when at least 100 developers contribute, growth in the developer base may cause additional links to cross the reporting threshold. This mechanism is more consequential for collaboration breadth than for intensity. Second, part of the increase reflects international ties that relocated developers brought to the destination countries. This transfer is a mechanism of interest rather than a measurement artefact: emigrants were disproportionately connected internationally (Wachs 2022), and their relocation transferred

these connections to the destination countries. Additional analyses show that collaboration among relocated developers accounts for little of the estimated effect (Section 5.5).

The increase in collaboration was also accompanied by a change in the geographical orientation of the destinations' networks. Figure 6 maps collaboration by partner economy for the three countries. In 2021, most collaboration was with the United States and Russia. By 2023, the arc to Russia was the widest on the map, consistent with relocated developers maintaining ties with former colleagues, while numerous new links extended to Europe and Asia. By 2025, the Russian arc had narrowed and links to Europe formed the densest part of the network. Correspondingly, the share of Russia and Belarus in total collaboration weight rose sharply in 2022 but fell below its 2021 level by 2025, when Europe had become the largest partner region (Online Appendix, Figure A2).

Figure 6. Collaboration of the GMA group by partner economy, 2021, 2023 and 2025



Note: Arc width: collaboration weight per 1,000 developer accounts in the three countries (quarterly mean, same scale in all years). Colour: partner region. Arcs connect national capitals. Links among the three countries are omitted.

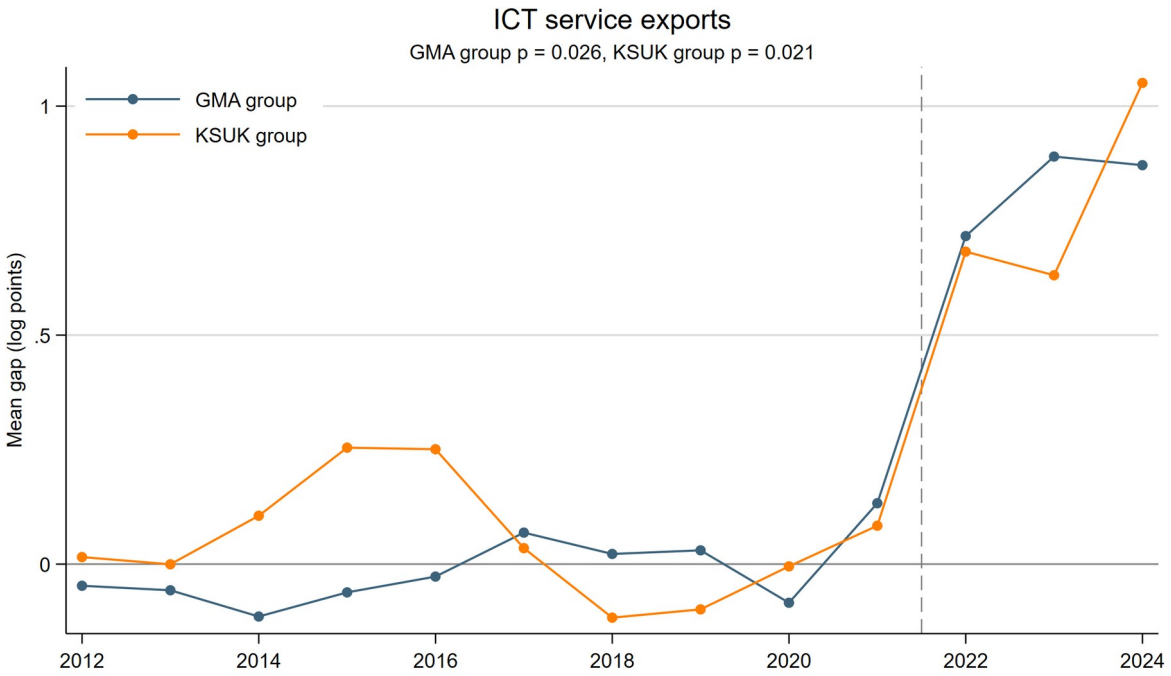
Region-specific synthetic controls show that this westward reorientation reflects the relocation shock rather than a general trend in GitHub collaboration. Relative to their synthetic controls, collaboration per account with partners in the EU, EFTA, the United Kingdom, the United States and Canada, excluding the destinations listed in Wachs (2022,

Table 3), increased by 1.49 log points ($p < 0.001$). The effect remained approximately as large in 2024–2025 as during the first eighteen months after the invasion: 1.46 compared with 1.57 log points (Online Appendix, Table A14 and Figure A3). In the KSUK group, the corresponding effect was 0.58 log points. Collaboration with the rest of the world also increased, by 1.14 log points ($p = 0.003$), although the pre-treatment fit for this measure is poor. A synthetic control cannot be constructed for ties with Russia and Belarus because the war affected every country's collaboration with Russia and almost no economy in the donor pool reports such links. Taken together, the evidence indicates that relocation did more than reproduce Russian networks abroad: it integrated the destination countries more deeply into software-production networks in Europe and North America.

5.4 The KSUK group: Export gains without proportionate developer relocation

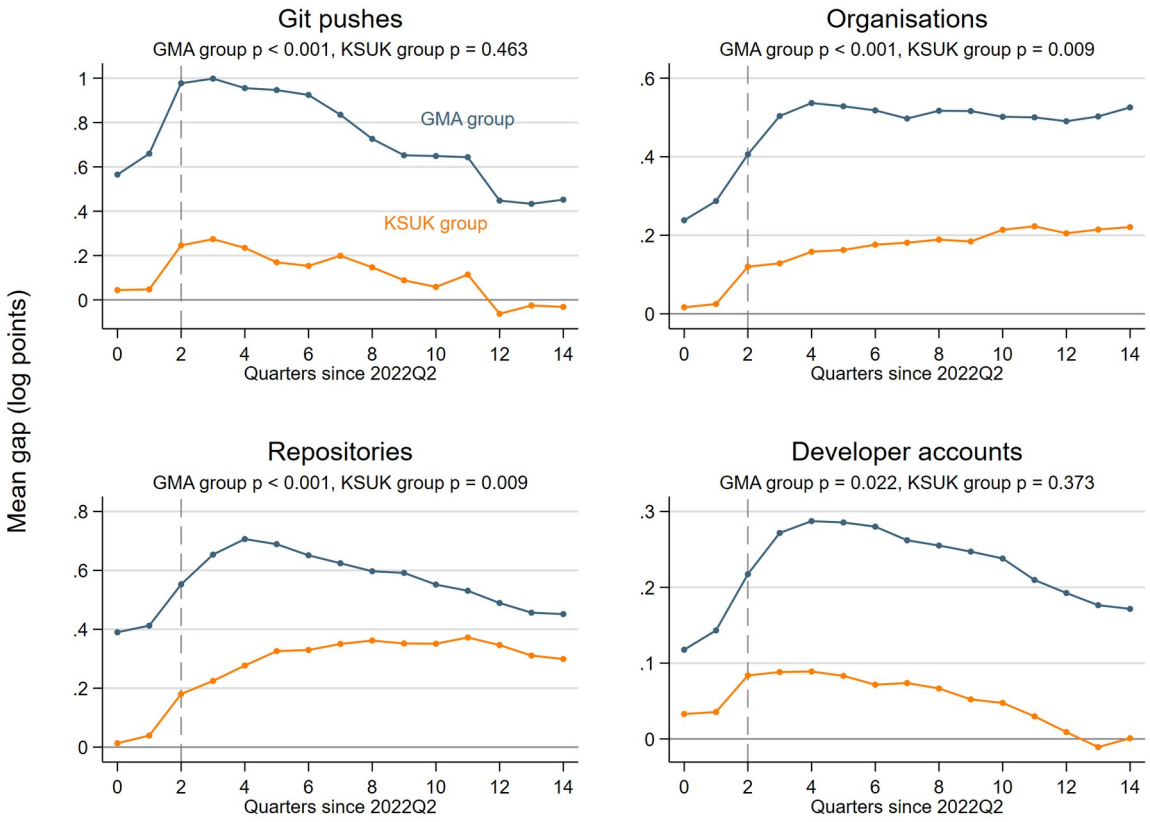
So far, we have focused on the GMA group and left aside the KSUK group because developer inflows were likely low in the latter group according to Wachs (2022). Nonetheless, the contrast between two groups is informative. Using the same approach as before, we see that although the KSUK countries experienced a comparatively low increase in software activity, their ICT service exports were 0.79 log points above their synthetic controls over 2022–2024, an effect similar in magnitude to that of the GMA group ($p = 0.021$ with the filter; Figure 7). The corresponding effects on software activity were substantially smaller. Git pushes increased by 0.11 log points ($p = 0.46$), organisations by 0.16 log points, and repositories by 0.28 log points ($p = 0.009$ for both), equivalent to between one-seventh and one-half of the GMA estimates. Collaboration intensity increased by 0.22 log points ($p = 0.20$), approximately one-sixth of the GMA effect. Figure 8 illustrates this divergence: in the KSUK group, the push gap remains below 0.3 log points throughout the post-treatment period and returns to approximately zero, or slightly below it, from 2025Q2 onward. Large export gains combined with limited and temporary changes in software activity are therefore less consistent with a substantial transfer of software labour. Although the underlying mechanisms cannot be identified causally, bilateral trade data and evidence on firm registration provide indications of alternative channels.

Figure 7. Mean gaps in ICT service exports, GMA group against KSUK group, 2012–2024



Note: Unweighted group means of the annual synth gaps. p-values for the pooled effect over 2022–2024, placebos with at most five times the pre-period MSPE of the destination.

Figure 8. Mean gaps in GitHub outcomes in event time, GMA group against KSUK group



Note: Unweighted group means of the quarterly synth gaps. Dashed line: 2022Q4. p-values for the pooled effect over 2022Q2–2025Q4 with all placebos.

Additional data is only partly available. Thus, our account remains descriptive and somewhat fragmented. Nonetheles, it hints to increased sales to Russian clients and the administrative relocation of firms or contracts as two alternative mechanisms. Serbia provides the clearest evidence of the first. Its ICT service exports to Russia, as reported by Serbia to Eurostat, rose from €5 million in 2021 to €20 million in 2022, €24 million in 2023, €255 million in 2024, and €224 million in 2025 (Eurostat 2026; Online Appendix, Table A17). The sharp increase thus occurred in 2024, after the EU ban on enterprise software and in the year in which the United States prohibited the provision of IT services to persons in Russia (OFAC 2024), rather than immediately after the invasion.

Kazakhstan is more consistent with administrative relocation, although the bilateral data are less informative. Its computer-service exports rose from US$60 million in 2021 to US$840 million in 2024 and US$1.14 billion in 2025. The National Bank assigns almost all of this increase to no partner country. Specifically, exports without an identified destination rose

from US$37 million in 2021 to US$730 million in 2024 and US$1.06 billion in 2025, accounting for 93 % of the total in 2025 (National Bank of Kazakhstan 2026; Online Appendix, Table A18). The missing destinations prevent direct attribution to Russia. Nevertheless, several pieces of evidence are consistent with Russian-linked business relocation. Among identified partners in the official statistics, exports to Cyprus and the United Arab Emirates, common locations of Russian holding companies (Ledyaeva et al. 2015), rose from US$3 million in 2021 to US$55 million in 2023. Astana Hub, whose member firms accounted for more than half of Kazakhstan's ICT service exports in 2025, lists Russia, Cyprus, and the United Arab Emirates, alongside the United States and the United Kingdom, among its members' principal export markets (DigitalBusiness.kz 2026).

Evidence from firm registrations and payment channels reinforces this interpretation across the KSUK group. In Kazakhstan, the post-2022 growth of ICT service exports has been attributed mainly to an increasing number of firms with foreign, predominantly Russian, capital (Dodonov 2024). By October 2022, more than 70 Russian IT companies had registered as residents of Kyrgyzstan's High Technology Park (DigitalBusiness.kz 2022). Regional payment channels were also used: in January 2025, the United States sanctioned a Kyrgyz bank for violating sanctions against Russia (OCCRP 2025). While we emphasize that such re-registration does not necessarily violate sanctions, the available evidence suggests that boost in ICT exports in the KSUK group may have been driven by company and holding relocations or increased sales to Russia without however proportionate relocations of development activity.

5.5 Robustness

We assess the robustness of the main findings along eight dimensions. We first test whether the annual export effects represent a discrete break after the invasion rather than a continuation of pre-existing trends. We then examine the sensitivity of the estimates to individual destinations, the placebo filter, the short pre-treatment period for the quarterly outcomes, and the extension of the export window to 2025. Moreover, we broaden the composition of the destination group and assess two potential alternative explanations for the GitHub results: collaboration among relocated developers and location misclassification due to VPN use. Finally, we consider whether other shocks in the destination countries could account for the observed effects. Table 2 summarises the corresponding pooled estimates where applicable.

Pre-existing export trends. The main identification concern in the annual analysis is that the post-2021 gaps may reflect a continuation of earlier export trends rather than a discrete response to the invasion. This concern is particularly relevant for Georgia and Armenia, where ICT exports grew rapidly before 2022 (Table 1). We assess it using a break test that compares, for each destination, the change in the gap from 2021 to the 2022–2024 mean with the corresponding change around each fictitious treatment year from 2012 to 2019 (Table A8). For all three destinations, the break between 2021 and the post-treatment period exceeds each of the eight placebo breaks, yielding the smallest attainable p-value of 1/9. Relative to the in-space placebos, the pooled break is 0.69 log points (p = 0.059 with the filter; Table A9).

Table 2. Robustness of the pooled effects, GMA group

	Exports (US$)	Exports (local curr.)	Git pushes	Orgs.	Repos.	Accounts	Collab. intensity
Main estimate	0.83	0.89	0.72	0.47	0.56	0.22	1.34
	(0.026)	(0.008)	(<0.001)	(<0.001)	(<0.001)	(0.022)	(<0.001)
Placebo filter 2×	0.83	0.89					
	(<0.001)	(0.004)					
Placebo filter 20×	0.83	0.89					
	(0.077)	(0.055)					
No placebo filter	0.83	0.89					
	(0.123)	(0.106)					
Through 2025 (21 donors)	0.90						
	(0.014)						
Without Georgia	0.53	0.53	0.73	0.50	0.47	0.19	1.33
	(0.092)	(0.097)	(0.002)	(<0.001)	(0.002)	(0.043)	(<0.001)
Without Montenegro	0.98	1.14	0.64	0.35	0.50	0.17	1.35
	(0.027)	(0.010)	(0.007)	(<0.001)	(0.001)	(0.060)	(<0.001)
Without Armenia	0.96	1.00	0.80	0.57	0.69	0.31	1.35
	(0.028)	(0.023)	(0.001)	(<0.001)	(<0.001)	(0.018)	(<0.001)
Five destinations	0.73	0.85	0.50	0.35	0.38	0.16	0.95
	(0.008)	(0.001)	(0.001)	(<0.001)	(<0.001)	(0.023)	(<0.001)
Two predictors (quarterly)			0.63	0.43	0.59	0.17	1.33
			(0.002)	(<0.001)	(<0.001)	(0.061)	(<0.001)
Synthetic DiD (quarterly)			0.56	0.44	0.46	0.16	1.27
			(0.005)	(<0.001)	(<0.001)	(0.130)	(<0.001)
Excl. links among destinations							1.26
							(<0.001)

Note: Orgs.: organisations. Repos.: repositories. Pooled synth effects in log points, p-values in parentheses (equation (6), 10,000 draws). Main estimates: annual outcomes with placebos whose pre-period MSPE is at most five times that of the destination, quarterly outcomes with all placebos. Leave-one-out rows pool the two remaining destinations. Five destinations: Georgia, Armenia, Montenegro, Serbia and Kazakhstan. Through 2025: donors reporting ICT service exports for 2025, 2022–2025 (Online Appendix, Table A19). Excl. links among destinations: without Russia, Belarus and the eleven economies in Wachs (2022, Table 3), 42 donors. Two predictors: outcome means of 2020 and 2021 only. Synthetic DiD: Arkhangelsky et al. (2021), p-values from 500 placebo replications. Full results: Online Appendix, Table A16.

Individual destinations. No single country drives the activity and collaboration results. Excluding one destination at a time leaves the effect on git pushes between 0.64 and 0.80 log points, on organisations between 0.35 and 0.57 and on repositories between 0.47 and 0.69, all with p < 0.01, and the collaboration effect between 1.33 and 1.35. The account effect ranges from 0.17 to 0.31 and loses significance at the 5 % level only without Montenegro (p =

0.060). The export estimate is more sensitive: without Georgia the pooled effect of Montenegro and Armenia falls to 0.53 log points ($p = 0.092$), while without Montenegro or Armenia it rises to about 0.97 ($p < 0.03$).

Placebo filter. Among the main results, only inference for the export effect depends on the placebo filter. The point estimate is unchanged, but the p-value is below 0.001 when placebos are restricted to those with pre-period MSPE at most twice that of the destination, 0.026 at five times, 0.077 at twenty times and 0.12 without a filter. Poorly fitted placebos produce large post-treatment gaps and widen the reference distribution, although a placebo whose pre-treatment path the synthetic control does not reproduce says little about an unaffected export trajectory (Abadie et al. 2010). This applies to many of the 52 donors, whose export series are heterogeneous and often volatile. The significance of the pooled export effect nevertheless depends on this restriction. A test that needs no threshold points the same way for the largest destination: with the ratio of post- to pre-period RMSPE as statistic, Georgia's effect has $p = 0.038$ among all 52 placebos (Table A3). The local-currency estimates show the same pattern.

Extension to 2025. The main export window ends in 2024 because only 21 of the 52 donors report ICT service exports for 2025. With the donor pool restricted to these 21 countries and 2025 deflated with the US consumer price index of the Bureau of Labor Statistics (2026), the pooled export effect of the GMA group is 0.87 log points over 2022–2024 and 0.90 over 2022–2025 ($p = 0.005$ and 0.014 with the filter, Online Appendix, Table A19). In 2025 alone, the gap is 1.00 log points ($p = 0.078$). It is large in Georgia (1.86) and Armenia (0.95) and small in Montenegro (0.19). By equation (5), the three countries exported about US$2.0 billion more in 2025 than their synthetic controls. The export gain therefore did not fade after 2024.

Short pre-period. The quarterly synthetic controls rest on eight pre-treatment quarters, and with one lag per quarter as predictor the close fit may partly reflect overfitting (Abadie 2021; Kaul et al. 2022). We therefore re-estimate the quarterly effects with only the 2020 and 2021 outcome means as predictors, and with synthetic difference in differences, which does not require an exact pre-treatment fit (Arkhangelsky et al. 2021). With two predictors no placebo is fitted exactly, yet the pooled estimates remain similar: 0.63 log points for git pushes, 0.43 for organisations, 0.59 for repositories and 1.33 for collaboration intensity, all with $p < 0.01$ (Table 2). The synthetic difference-in-differences estimates are 0.56, 0.44, 0.46 and 1.27, again with $p < 0.01$. A conventional difference in differences without unit weights gives smaller effects for git pushes and repositories, 0.47 and 0.40 (Online Appendix, Table A16).

Developer accounts are the exception: their effect falls to 0.16 to 0.17 log points and is no longer significant at the 5 % level ($p = 0.061$ and 0.13), consistent with the slow adjustment of this measure (Section 5.2). Armenia's push effect is the least stable across estimators, ranging from 0.10 to 0.57 log points.

Composition of the GMA group. The baseline selection rule ranks destinations by developer inflows relative to the size of their pre-existing developer base (Section 2.4). Broadening the group to include Serbia and Kazakhstan, two KSUK destinations that received many Russian migrants in absolute terms (Section 2.3), produces an export effect of 0.73 log points ($p = 0.008$) and statistically significant effects for all GitHub outcomes. As expected if the effects increase with relative inflows, the activity and collaboration estimates are smaller than those for the GMA group, ranging from 0.16 log points for developer accounts to 0.95 for collaboration intensity.

Links among relocated developers. Part of the collaboration gain may reflect continued cooperation among developers who moved to different destinations, such as a developer in Tbilisi working with a former colleague in Yerevan. Excluding links with all eleven destinations in Wachs (2022, Table 3), in addition to Russia and Belarus, lowers the intensity effect only from 1.34 to 1.26 log points ($p < 0.001$). The gain therefore reflects collaboration with the rest of the world rather than ties within the emigrant network.

Location by IP address. A developer who stays in Moscow but connects through a VPN server in Tbilisi is recorded in Georgia, so exit servers in the destinations could inflate their activity effects. This cannot easily produce our cross-country pattern, because the IP-based effects align with the relocations that Wachs (2022) identified from profile locations, which a VPN does not change (Section 5.2). VPN users would also have had to edit their profiles, in similar proportions across destinations.

Other shocks in the destinations. Armenia received more than 100,000 refugees from Nagorno-Karabakh in late September 2023 (Gevorgyan 2023). With outcomes measured per capita, an inflow with few developers would lower rather than raise Armenia's effects. Between 2022Q2–2023Q3 and 2023Q4–2025Q4, Armenia's gaps change largely in line with those of Georgia and Montenegro (Online Appendix, Table A15), so the refugee inflow does not account for the GMA-group effects and, if anything, leads us to understate Armenia's contribution in later quarters. Ukrainian refugees went mostly to the EU, which we exclude from the donor pool (Section 4).

6 Discussion

Georgia, Montenegro and Armenia gained substantially from Russia's invasion of Ukraine. Their ICT service exports exceeded the counterfactual by about US$3.3 billion over 2022 to 2024, software activity rose in proportion to the developer inflows documented by Wachs (2022), and collaboration with partners outside Russia and Belarus nearly quadrupled per developer. The three countries thus acquired not only productive capacity but also part of Russia's international network position.

The collaboration results connect this episode to the literature on skilled emigration. Waldinger (2016) shows that the loss of scientists impaired German departments for decades, whereas destroyed physical capital was replaced within a few years. The post-2022 relocation shows the counterpart in receiving economies: developers who left Russia were disproportionately connected internationally (Wachs 2022), and the countries that received them acquired such ties within two quarters of the invasion (Figure 5). Although software activity declined from its peak, organisations and international collaboration showed no comparable reversal by the end of 2025, which points to a partial institutionalisation of the initial human-capital shock.

6.1 Implications for innovation, research and economic policy

The relocation was not caused by policies in the destination countries. Instead, it was an exogenous shock triggered by the war, sanctions, and Russia's mobilisation. However, the extent to which destination countries retained the resulting gains depended partly on their policy choices. Our findings have implications for three policy areas.

The first area is residence policy. Gains embodied in workers, organisations, and professional networks persisted through 2025 and were largest where inflows were substantial relative to the existing developer base. Inflows equivalent to 42–94 % of that base transformed the software sectors of Georgia, Armenia, and Montenegro, whereas similar absolute inflows had much smaller effects in the larger sectors of Serbia and Kazakhstan. Visa-free access shaped developers' initial destination choices (Section 2.3), while residence permits for remote workers and their families, access to banking services, and straightforward company registration are more likely to influence whether they remain and employ local workers. Although our data do not permit these instruments to be ranked, they indicate the magnitude of the benefits at stake. In Georgia, Armenia, and Montenegro, export gains valued at 2021 prices amounted to 3.8–8.3 % of 2021 GDP and were accompanied by links to software

networks in Europe and North America that small economies rarely develop so rapidly. Montenegro's plan to introduce visa requirements for Russian citizens from November 2026 (Meduza 2026a) and Armenia's stricter residency rules (Meduza 2026b) reflect a trade-off between security and EU-accession objectives, on the one hand, and these economic benefits, on the other. Admission policies based on individual screening rather than blanket restrictions could mitigate this trade-off.

The second area is the treatment of firms. Preferential regimes for IT companies may attract registrations without attracting developers. Russian-owned firms relocated to technology parks in Kazakhstan and Kyrgyzstan (Dodonov 2024; DigitalBusiness.kz 2022), yet software activity in the KSUK group increased far less than exports. Where governments seek to develop domestic software capacity rather than merely attract billing activity, incentives linked to local employment and development work are therefore more likely to achieve this objective.

The third area is sanctions policy. When developers relocate, the origin country loses workers, tax revenue, and international professional ties, while destination countries acquire these resources. When only contracts or invoicing relocate, however, the underlying business activity may remain substantively Russian. Restrictions on IT services are typically linked to a firm's place of registration and the location of its bank account (Section 2.2). For digitally delivered services, establishing an affiliate in a non-sanctioning country may therefore be sufficient to preserve client relationships. Serbia's ICT service exports to Russia increased in 2024, when the EU ban on enterprise software became fully effective and the United States prohibited the provision of IT services to persons in Russia. This pattern suggests third-country substitution similar to that documented for goods by Chupilkin, Javorcik and Plekhanov (2026). Effective anti-circumvention rules for services would therefore need to consider beneficial ownership and the location of production rather than relying solely on the place of registration. Travel restrictions also shaped the geographical distribution of productive capacity. After several EU member states closed their borders to Russian tourists in 2022 (Section 2.2), departing developers moved predominantly to visa-free destinations outside the EU, which consequently captured a substantial share of the capacity lost by Russia. The European Commission suspended research and innovation cooperation with Russian entities in March 2022 (European Commission 2022). Our collaboration results indicate that some of the international ties of relocated developers shifted with them to the destination countries.

6.2 Limitations and future research

Several limitations define the scope of these conclusions. The first concerns the measurement of software activity, which the Innovation Graph records only for public activity and above a reporting threshold (Section 3). Administrative firm registers and employer records could complement these data by showing how many workers Russian-founded firms employ and how much tax they pay. Nearly 30,000 companies were founded by Russians in Georgia in the two years after the invasion (Kyiv Independent 2024), which makes such records a promising measure of the windfall that is independent of GitHub.

The second concerns the link between the export and activity effects. Each has a causal interpretation, but the data do not show whether one causes the other or whether both stem from the same shock. Exports and software activity rose within the same half-year, yet the timing does not establish how much of the export gain relocated developers produced. Quarterly balance-of-payments data for more countries and bilateral services data by partner would permit sharper tests.

Third, the analysis does not identify why the KSUK group experienced export gains without a comparable increase in developer activity. Serbia’s growing sales to Russian clients and Kazakhstan’s large share of geographically unallocated service exports are consistent with the relocation of contracts or invoicing, but aggregate bilateral statistics cannot distinguish these channels. Transaction-level payment data or firm-level trade-in-services records could determine whether the additional exports originated in firms that also employed developers locally. Such evidence would extend to services the analysis of rerouted trade in goods by Chupilkin, Javorcik and Plekhanov (2026).

Finally, the observation period ends in 2025. The durability of the windfall depends on whether developers and firms remain after the access conditions that initially favoured these destinations change. Montenegro plans to end visa-free entry for Russian citizens in November 2026 (Meduza 2026a), while Armenia is tightening its residency rules (Meduza 2026b). These policy changes provide a prospective test of whether relocated firms and professional networks have become sufficiently embedded to persist after the original mobility advantage diminishes.

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Online Appendix

Russia's Software Developer Exodus after the Ukraine Invasion: Export Gains and Network Integration in Visa-Free Destinations

Torben Schubert

Table A1. Descriptive statistics, 2021, all columns

	Population (mn)	GDP per capita (US$)	ICT exports 2021 (US$ mn)	ICT exports per capita (US$)	ICT exports (% of GDP)	ICT export growth 2015–21 (%)	ICT exports 2024 (US$ mn)	Developer accounts	Accounts per 1,000 inhabitants	Pushes per account	Partner economies	Inflow (% of 2021 developers)
Georgia	3.71	5175.20	215.88	58.21	1.15	26.13	842.27	48324.75	13.03	1.45	11.75	94.00
Armenia	2.96	4264.80	382.37	129.08	2.76	17.91	1180.57	47354.25	15.99	1.55	10.25	42.00
GMA group (mean)	2.43	5546.10	239.73	126.92	1.99	18.04	747.25	34502.92	13.85	1.48	9.17	69.67
Kazakhstan	19.74	10873.39	191.91	9.72	0.10	4.93	999.64	115893.75	5.87	1.21	8.00	13.00
Serbia	6.83	7465.68	2191.47	320.66	3.31	19.58	4470.35	136377.00	19.95	1.46	29.25	8.00
Uzbekistan	34.24	3952.00	176.27	5.15	0.22	-2.65	619.74	60778.50	1.77	1.94	6.75	8.00
Kyrgyz Republic	6.85	1132.55	13.53	1.98	0.15	-19.04	383.41	27359.75	3.99	2.33	4.25	7.00
KSUK group (mean)	16.92	5855.90	643.29	84.37	0.94	0.70	1618.28	85102.25	7.90	1.74	12.06	9.00
Russian Federation	144.75	10231.32	7232.31	49.97	0.40	10.15	2385.98	1936721.50	13.38	2.03	76.75	
Donors, median (n = 52)	5.85	3983.03	99.99	11.29	0.29	3.33	130.66	23541.13	4.24	0.99	4.25	

Note: Values for 2021 unless stated otherwise. GDP per capita in constant US dollars, ICT service exports in million current US dollars (WDI). ICT export growth: mean annual log growth 2015–2021. Accounts: GitHub developer accounts, mean of 2021Q1–Q4. Partners: economies with a reported collaboration link. Inflow: Russian and Belarusian developers in % of 2021 developers (Wachs 2022, Table 3). Group rows: unweighted means. Donors: median of the donor pool of the annual export models.

Table A2. Value added in information and communication (NACE section J), destination economies

Economy	Share 2021 (%)	Share 2025 (%)	Change in share 2021–25 (pp)	Growth of J 2017–21 (%)	Growth of J 2022–25 (%)	Growth of total 2017–21 (%)	Growth of total 2022–25 (%)	Relative acceleration of J (pp)	Volume of J 2025 (2021 = 100)
Georgia	3.5489	8.0319	4.4830	13.3838	34.1810	4.9045	8.9813	16.7204	324.1632
Montenegro	4.5869	5.1085	0.5215	2.7761	7.1438	2.0430	4.2652	2.1456	131.7857
Armenia	4.1585	6.5203	2.3618	7.6751	27.3347	3.5939	8.6189	14.6347	262.8983
GMA group (mean)	4.0981	6.5536	2.4554	7.9450	22.8865	3.5138	7.2885	11.1669	239.6157
Kazakhstan	2.4681	2.7127	0.2446	6.8557	4.7888	2.8661	4.8920	-4.0928	120.5755
Serbia	7.4590	10.3962	2.9373	8.9495	9.9805	3.9222	3.2180	1.7353	146.3064
Kyrgyz Republic	3.0641	2.6282	-0.4358	-2.5945	8.4484	2.1854	10.1439	3.0843	138.3223
Uzbekistan	1.6507	2.9527	1.3019	19.0092	24.1175	5.3763	6.6982	3.7863	237.3184
KSUK group (mean)	3.6605	4.6725	1.0120	8.0550	11.8338	3.5875	6.2380	1.1283	160.6306

Note: Section J (information and communication). Share: gross value added of J in % of total gross value added, current prices. g: mean annual real growth of J and of the total economy, 2017–2021 and 2022–2025. Relative acceleration: growth of J minus growth of the total, after minus before, percentage points. Volume of J 2025: chain-linked, 2021 = 100. Sources: national statistical offices and Eurostat, 2024–2025 partly preliminary. Group rows: unweighted means.

Table A3. Annual estimates by destination, ICT service exports

Outcome	Destination	Group	Pre-period start	Effect	Effect (%)	Pre-period RMSPE	p (5×)	Placebos (5×)	p (all)
ICT exports (US$)	Armenia	GMA	2005	0.5567	74.4860	0.1190	0.1786	27	0.1132
ICT exports (US$)	Georgia	GMA	2005	1.4097	309.4649	0.1799	0.0526	37	0.0377
ICT exports (US$)	Kazakhstan	KSUK	2005	0.7035	102.0802	0.0869	0.1000	19	0.0377
ICT exports (US$)	Kyrgyz Republic	KSUK	2005	1.2089	234.9814	0.3574	0.1364	43	0.1132
ICT exports (US$)	Serbia	KSUK	2007	0.4522	57.1824	0.0981	0.2917	23	0.1509
ICT exports (US$)	Uzbekistan	KSUK	2005	0.7868	119.6288	0.4553	0.4792	47	0.4528
ICT exports (local currency)	Armenia	GMA	2005	0.6596	93.4060	0.1406	0.2143	27	0.1250
ICT exports (local currency)	Georgia	GMA	2005	1.6104	400.4700	0.4344	0.2093	42	0.1875
ICT exports (local currency)	Kazakhstan	KSUK	2005	0.8533	134.7469	0.1034	0.0909	21	0.0417
ICT exports (local currency)	Kyrgyz Republic	KSUK	2005	1.7958	502.4115	0.3768	0.1429	41	0.1250
ICT exports (local currency)	Serbia	KSUK	2007	0.7159	104.6034	0.2407	0.3077	38	0.2500
ICT exports (local currency)	Uzbekistan	KSUK	2013	0.2668	30.5720	0.1250	0.5556	35	0.4792

Note: ICT exports (US$): log real ICT service exports per capita (2021 US dollars). ICT exports (local currency): deflated with the GDP deflator. Effect: mean gap 2022–2024 in log points, Effect (%) = 100 × (exp(effect) − 1). p: rank of the ratio of post- to pre-period RMSPE among in-space placebos. 5× (main): placebos whose pre-period MSPE is at most five times that of the destination. All: all placebos. Placebos: number of placebos used.

Table A4. Export gains and developer accounts in levels

Panel	Economy	Measure	Unit	Value	Band, 5 %	Band, 95 %	p
A Destination exports	Georgia	additional exports 2022	US$ mn, 2021 prices	395.40			
A Destination exports	Georgia	additional exports 2023	US$ mn, 2021 prices	625.33			
A Destination exports	Georgia	additional exports 2024	US$ mn, 2021 prices	551.86			
A Destination exports	Georgia	additional exports 2022-24	US$ mn, 2021 prices	1572.59	762.41	1763.80	
A Destination exports	Georgia	additional exports 2022-24	US$ mn, current	1769.08	858.22	1984.05	
A Destination exports	Georgia	additional exports 2022-24	% of GDP 2021	8.34			
A Destination exports	Armenia	additional exports 2022	US$ mn, 2021 prices	205.60			
A Destination exports	Armenia	additional exports 2023	US$ mn, 2021 prices	454.45			
A Destination exports	Armenia	additional exports 2024	US$ mn, 2021 prices	487.37			
A Destination exports	Armenia	additional exports 2022-24	US$ mn, 2021 prices	1147.42	-775.30	1581.20	
A Destination exports	Armenia	additional exports 2022-24	US$ mn, current	1297.28	-868.11	1785.81	
A Destination exports	Armenia	additional exports 2022-24	% of GDP 2021	8.27			
A Destination exports	Serbia	additional exports 2022	US$ mn, 2021 prices	637.20			
A Destination	Serbia	additional	US$ mn, 2021	1253.05			

Panel	Economy	Measure	Unit	Value	Band, 5 %	Band, 95 %	p
exports		exports 2023	prices				
A Destination exports	Serbia	additional exports 2024	US$ mn, 2021 prices	1743.58			
A Destination exports	Serbia	additional exports 2022-24	US$ mn, 2021 prices	3633.83	-2358.17	5962.44	
A Destination exports	Serbia	additional exports 2022-24	US$ mn, current	4115.69	-2629.46	6736.99	
A Destination exports	Serbia	additional exports 2022-24	% of GDP 2021	5.49			
A Destination exports	Kazakhstan	additional exports 2022	US$ mn, 2021 prices	270.74			
A Destination exports	Kazakhstan	additional exports 2023	US$ mn, 2021 prices	312.42			
A Destination exports	Kazakhstan	additional exports 2024	US$ mn, 2021 prices	359.18			
A Destination exports	Kazakhstan	additional exports 2022-24	US$ mn, 2021 prices	942.34	320.50	1159.45	
A Destination exports	Kazakhstan	additional exports 2022-24	US$ mn, current	1059.52	357.45	1304.65	
A Destination exports	Kazakhstan	additional exports 2022-24	% of GDP 2021	0.48			
A Destination exports	Kyrgyz Republic	additional exports 2022	US$ mn, 2021 prices	20.08			
A Destination exports	Kyrgyz Republic	additional exports 2023	US$ mn, 2021 prices	40.85			
A Destination exports	Kyrgyz Republic	additional exports 2024	US$ mn, 2021 prices	286.32			
A Destination exports	Kyrgyz Republic	additional exports 2022-24	US$ mn, 2021 prices	347.25	132.48	415.55	
A Destination exports	Kyrgyz Republic	additional exports 2022-24	US$ mn, current	399.08	152.99	477.33	
A Destination exports	Kyrgyz Republic	additional exports 2022-24	% of GDP 2021	3.75			
A Destination exports	Uzbekistan	additional exports 2022	US$ mn, 2021 prices	119.87			
A Destination exports	Uzbekistan	additional exports 2023	US$ mn, 2021 prices	185.99			
A Destination exports	Uzbekistan	additional exports 2024	US$ mn, 2021 prices	350.85			
A Destination exports	Uzbekistan	additional exports 2022-24	US$ mn, 2021 prices	656.71	-212.10	949.05	
A Destination exports	Uzbekistan	additional exports 2022-24	US$ mn, current	744.77	-237.09	1075.14	
A Destination exports	Uzbekistan	additional exports 2022-24	% of GDP 2021	0.81			
A Destination exports	Seven destinations	additional exports 2022-24	US$ mn, 2021 prices	8520.40	-318.99	9966.66	
A Destination exports	Seven destinations	additional exports 2022-24	US$ mn, current	9632.59	-329.84	11256.95	
A Destination exports	Six destinations (without Serbia)	additional exports 2022-24	US$ mn, 2021 prices	4886.58	-1466.67	5075.91	
A Destination exports	Six destinations (without Serbia)	additional exports 2022-24	US$ mn, current	5516.90	-1646.02	5729.78	
A Destination exports	GMA group	additional exports 2022-24	US$ mn, 2021 prices	2940.27	176.51	3295.64	
A Destination exports	GMA group	additional exports 2022-24	US$ mn, current	3313.52	202.09	3714.02	
A Destination exports	KSUK group	additional exports 2022-24	US$ mn, 2021 prices	5580.13	-2408.49	7823.99	
A Destination exports	KSUK group	additional exports 2022-24	US$ mn, current	6319.07	-2691.20	8838.96	
A Destination exports	GMA group	additional exports 2022-24	% of GDP 2021	7.63			
A Destination exports	KSUK group	additional exports 2022-24	% of GDP 2021	1.58			
B Russia exports	Russian Federation	ICT exports 2021	US$ mn, current	7232.31			
B Russia exports	Russian Federation	ICT exports 2022	US$ mn, current	5831.35			
B Russia exports	Russian Federation	ICT exports 2023	US$ mn, current	2883.56			
B Russia exports	Russian Federation	ICT exports 2024	US$ mn, current	2385.98			
B Russia exports	Russian Federation	ICT exports 2025	US$ mn, current	2698.03			
B Russia exports	Russian Federation	export gap 2022-24 vs	US$ mn, current	10596.04			

Panel	Economy	Measure	Unit	Value	Band, 5 %	Band, 95 %	p
		2021 level					
B Russia exports	Russian Federation	export gap 2022-24 vs trend 2015-21	US$ mn, current	12430.06			
B Russia exports	Seven destinations	additional exports / RU gap (level)	ratio	0.91			
B Russia exports	Seven destinations	additional exports / RU gap (trend)	ratio	0.77			
B Russia exports	Six destinations (without Serbia)	additional exports / RU gap (level)	ratio	0.52			
B Russia exports	Six destinations (without Serbia)	additional exports / RU gap (trend)	ratio	0.44			
B Russia exports	GMA group	additional exports / RU gap (level)	ratio	0.31			
B Russia exports	GMA group	additional exports / RU gap (trend)	ratio	0.27			
B Russia exports	KSUK group	additional exports / RU gap (level)	ratio	0.60			
B Russia exports	KSUK group	additional exports / RU gap (trend)	ratio	0.51			
C Developer accounts	Georgia	additional accounts, mean 2022Q2-24Q4	accounts	29718.47	18659.23	43667.52	
C Developer accounts	Georgia	additional accounts	% of stock 2021	61.50			
C Developer accounts	Armenia	additional accounts, mean 2022Q2-24Q4	accounts	6820.94	-3783.26	20196.04	
C Developer accounts	Armenia	additional accounts	% of stock 2021	14.40			
C Developer accounts	Serbia	additional accounts, mean 2022Q2-24Q4	accounts	9527.50	-17093.12	43104.14	
C Developer accounts	Serbia	additional accounts	% of stock 2021	6.99			
C Developer accounts	Kazakhstan	additional accounts, mean 2022Q2-24Q4	accounts	20622.41	-6163.28	54407.25	
C Developer accounts	Kazakhstan	additional accounts	% of stock 2021	17.79			
C Developer accounts	Cyprus	additional accounts, mean 2022Q2-24Q4	accounts	4614.00	-1026.00	11727.74	
C Developer accounts	Cyprus	additional accounts	% of stock 2021	20.08			
C Developer accounts	Kyrgyz Republic	additional accounts, mean 2022Q2-24Q4	accounts	5057.10	-2278.27	14309.23	
C Developer accounts	Kyrgyz Republic	additional accounts	% of stock 2021	18.48			
C Developer accounts	United Arab Emirates	additional accounts, mean 2022Q2-24Q4	accounts	20055.12	-18261.47	68383.91	
C Developer accounts	United Arab Emirates	additional accounts	% of stock 2021	12.36			
C Developer accounts	Uzbekistan	additional accounts, mean 2022Q2-24Q4	accounts	5640.25	-15478.92	32277.91	
C Developer accounts	Uzbekistan	additional accounts	% of stock 2021	9.28			
C Developer accounts	Lithuania	additional accounts, mean 2022Q2-24Q4	accounts	9038.00	-7192.42	29509.46	
C Developer accounts	Lithuania	additional accounts	% of stock 2021	11.14			
C Developer accounts	Estonia	additional accounts, mean 2022Q2-24Q4	accounts	2047.51	-9171.52	16198.10	
C Developer accounts	Estonia	additional accounts	% of stock 2021	3.67			

Panel	Economy	Measure	Unit	Value	Band, 5 %	Band, 95 %	p
C Developer accounts	Russian Federation	accounts (gap), mean 2022Q2-24Q4	accounts	-6832.54	-411494.66	503568.66	0.83
C Developer accounts	Belarus	accounts (gap), mean 2022Q2-24Q4	accounts	-34242.16	-77406.57	20201.20	0.18
C Developer accounts	Seven destinations	accounts, mean 2022Q2-24Q4	accounts	82557.36	42107.39	153971.58	
C Developer accounts	Eleven economies (Wachs 2022)	accounts, mean 2022Q2-24Q4	accounts	118311.99	67929.57	221098.44	
C Developer accounts	Russia and Belarus	accounts, mean 2022Q2-24Q4	accounts	-41074.71	-472149.75	481323.19	
C Developer accounts	GMA group	accounts, mean 2022Q2-24Q4	accounts	41710.11	27329.58	61996.56	
C Developer accounts	Eleven economies / Russia and Belarus	additional / missing accounts	ratio	2.88			
C Developer accounts	Russian Federation	accounts, mean 2021	accounts	1936721.50			
C Developer accounts	GMA group	additional accounts / RU stock 2021	%	2.15			
C Developer accounts	Seven destinations	additional accounts / RU stock 2021	%	4.26			
C Developer accounts	Eleven economies (Wachs 2022)	additional accounts / RU stock 2021	%	6.11			

Note: Panel A: additional ICT service exports, actual × (1 − exp(−gap)), from the synth gap in ICT exports (US$), in 2021 and in current US dollars and in % of 2021 GDP. Bands: from the post-period gaps of in-space placebos (5× filter), for sums over economies the 5th and 95th percentiles of 10,000 draws. Panel B: Russia's ICT service exports (WDI) against a counterfactual without decline (2021 level or linear trend 2015–2021), descriptive. Panel C: additional developer accounts from the synth gap in accounts, mean 2022Q2–2024Q4, bands with all placebos. Accounts include inactive accounts and are located by IP address.

Table A5. Co-movement of the gaps in ICT service exports and git pushes

Group	Level	N	Pearson	Spearman
GMA group	Country-years	15	0.6950	0.7536
GMA group	Group mean by year	5	0.9638	1.0000
KSUK group	Country-years	20	0.1038	0.2872
KSUK group	Group mean by year	5	0.7401	0.7000

Note: Correlation between the annual synth gap in ICT service exports and the annual mean of the quarterly synth gap in git pushes, 2020–2024. Country-years: one observation per economy and year. Group mean by year: unweighted means over the group. Descriptive, no test.

Table A6. Quarterly ICT service exports and git pushes, Georgia and Armenia

Destination	Quarter	ICT exports (US$ mn)	ICT exports, log vs 2021 mean	Gap in git pushes
Georgia	2021Q1	43.5892	-0.2136	-0.0023
Georgia	2021Q2	54.3851	0.0077	-0.0097
Georgia	2021Q3	52.4835	-0.0279	0.0016
Georgia	2021Q4	65.4191	0.1924	-0.0020
Georgia	2022Q1	72.5175	0.2954	0.0513
Georgia	2022Q2	112.4558	0.7341	0.6333
Georgia	2022Q3	203.0327	1.3250	0.7066
Georgia	2022Q4	209.2335	1.3550	0.9329
Georgia	2023Q1	250.7875	1.5362	1.0132
Georgia	2023Q2	221.1806	1.4106	0.9600
Georgia	2023Q3	208.8729	1.3533	0.8780
Georgia	2023Q4	211.1258	1.3640	0.8047
Armenia	2021Q1	87.6770	-0.0864	0.0037
Armenia	2021Q2	86.2245	-0.1031	0.0192
Armenia	2021Q3	94.6238	-0.0102	0.0198
Armenia	2021Q4	113.8478	0.1748	0.0370
Armenia	2022Q1	155.7723	0.4883	0.0720
Armenia	2022Q2	193.4154	0.7047	0.5133

Destination	Quarter	ICT exports (US$ mn)	ICT exports, log vs 2021 mean	Gap in git pushes
Armenia	2022Q3	303.8868	1.1566	0.4857
Armenia	2022Q4	398.1338	1.4267	0.9330
Armenia	2023Q1	370.3657	1.3544	0.9041
Armenia	2023Q2	410.1557	1.4564	0.7534
Armenia	2023Q3	430.0000	1.5037	0.7156
Armenia	2023Q4	379.4713	1.3787	0.7305

Note: Quarterly ICT service exports (credit, million US dollars) from the balance of payments of the National Bank of Georgia and the Central Bank of Armenia. ICT exports: log relative to the 2021 quarterly mean, not adjusted for trend or seasonality. Gap in git pushes: synth gap in log git pushes per capita. Descriptive. Montenegro does not report ICT services quarterly.

Table A7. Granger-type tests, Georgia and Armenia

Direction	Lags	F	p	Sum of lag coefficients	N
Pushes → exports	1	2.9167	0.0960	0.3857	44
Exports → pushes	1	7.4493	0.0097	0.4269	44
Pushes → exports	2	1.3053	0.2847	0.5118	42
Exports → pushes	2	3.7981	0.0328	0.8069	42

Note: Panel of Georgia and Armenia, quarterly first differences. Exports: log ICT service exports (balance of payments). Pushes: synth gap in log git pushes per capita. Each row regresses the first series on its own lags and the lags of the other series, with country and quarter fixed effects and robust standard errors. F and p test that all lags of the other series are zero. Descriptive.

Figure A1. Quarterly ICT service exports and synth gap in git pushes, Georgia and Armenia

Note: Exports in logs relative to the 2021 mean, balance of payments data.

Table A8. Break test 2021/22, in space and in time

Frequency	Outcome	Statistic	Destination	Value	p (5×)	p (all)	Value, in time	p (in time)	Fictitious years
Annual	ICT exports (US$)	B1	Uzbekistan	0.6646	0.2917	0.3396	0.6646	0.5556	8
Annual	ICT exports (US$)	B1	Serbia	0.3282	0.2500	0.5094	0.4852	0.3333	8
Annual	ICT exports (US$)	B1	Kyrgyz Republic	1.2174	0.0909	0.1509	2.2084	0.1111	8
Annual	ICT exports (US$)	B1	Kazakhstan	0.6059	0.1500	0.3962	1.8416	0.1111	8
Annual	ICT exports (US$)	B1	Georgia	1.1535	0.1053	0.1698	1.2061	0.1111	8
Annual	ICT exports (US$)	B1	Armenia	0.6037	0.3214	0.4151	0.8573	0.1111	8

Frequency	Outcome	Statistic	Destination	Value	p (5×)	p (all)	Value, in time	p (in time)	Fictitious years
Annual	ICT exports (US$)	B2	Uzbekistan	0.5298	0.3542	0.3962	0.5298	0.4444	8
Annual	ICT exports (US$)	B2	Serbia	0.1552	0.5833	0.7358	0.2834	0.2222	8
Annual	ICT exports (US$)	B2	Kyrgyz Republic	0.8579	0.1591	0.2264	1.1845	0.1111	8
Annual	ICT exports (US$)	B2	Kazakhstan	0.8510	0.0500	0.2264	1.5347	0.1111	8
Annual	ICT exports (US$)	B2	Georgia	0.9992	0.0789	0.1887	1.0376	0.1111	8
Annual	ICT exports (US$)	B2	Armenia	0.4212	0.3214	0.4151	0.6154	0.1111	8
Annual	ICT exports (local currency)	B1	Uzbekistan	0.2974	0.4722	0.5208	0.3788	0.3333	2
Annual	ICT exports (local currency)	B1	Serbia	0.3535	0.3846	0.4167	0.3535	0.6667	8
Annual	ICT exports (local currency)	B1	Kyrgyz Republic	2.0829	0.0476	0.0833	1.9605	0.1111	8
Annual	ICT exports (local currency)	B1	Kazakhstan	0.8720	0.0909	0.2708	1.0064	0.1111	8
Annual	ICT exports (local currency)	B1	Georgia	0.8774	0.2093	0.2708	0.8774	0.1111	8
Annual	ICT exports (local currency)	B1	Armenia	0.4242	0.2857	0.4167	0.4227	0.1111	8
Annual	ICT exports (local currency)	B2	Uzbekistan	0.3872	0.2778	0.4167	0.3930	0.3333	2
Annual	ICT exports (local currency)	B2	Serbia	0.2581	0.4359	0.4792	0.2581	0.3333	8
Annual	ICT exports (local currency)	B2	Kyrgyz Republic	1.1564	0.1429	0.1667	0.9958	0.1111	8
Annual	ICT exports (local currency)	B2	Kazakhstan	0.6192	0.0455	0.2708	0.8076	0.1111	8
Annual	ICT exports (local currency)	B2	Georgia	0.8881	0.1395	0.1667	0.8881	0.1111	8
Annual	ICT exports (local currency)	B2	Armenia	0.2157	0.4643	0.5625	0.2136	0.2222	8
Quarterly	Git pushes	B1	Uzbekistan	-0.0364	0.8305	0.8167			
Quarterly	Git pushes	B1	Serbia	0.1667	0.4510	0.4500			
Quarterly	Git pushes	B1	Kyrgyz Republic	-0.0915	0.6735	0.6667			
Quarterly	Git pushes	B1	Kazakhstan	0.1227	0.4667	0.5167			
Quarterly	Git pushes	B1	Georgia	0.7172	0.0588	0.0333			
Quarterly	Git pushes	B1	Armenia	0.5306	0.0893	0.0833			
Quarterly	Git pushes	B2	Uzbekistan	-0.1656	0.4576	0.4500			
Quarterly	Git pushes	B2	Serbia	0.1423	0.5294	0.5167			
Quarterly	Git pushes	B2	Kyrgyz Republic	0.0915	0.6327	0.6333			
Quarterly	Git pushes	B2	Kazakhstan	-0.1715	0.3333	0.4500			
Quarterly	Git pushes	B2	Georgia	0.6353	0.0588	0.0500			
Quarterly	Git pushes	B2	Armenia	0.4763	0.0893	0.1000			
Quarterly	Organisations	B1	Uzbekistan	0.1732	0.1538	0.1408			
Quarterly	Organisations	B1	Serbia	0.1516	0.1429	0.1831			
Quarterly	Organisations	B1	Kyrgyz Republic	0.0895	0.3529	0.4085			
Quarterly	Organisations	B1	Kazakhstan	0.1858	0.2000	0.1127			
Quarterly	Organisations	B1	Georgia	0.4051	0.0154	0.0141			
Quarterly	Organisations	B1	Armenia	0.2723	0.0294	0.0141			
Quarterly	Organisations	B2	Uzbekistan	0.0192	0.5692	0.5915			

Frequency	Outcome	Statistic	Destination	Value	p (5×)	p (all)	Value, in time	p (in time)	Fictitious years
Quarterly	Organisations	B2	Serbia	0.0370	0.3265	0.4225			
Quarterly	Organisations	B2	Kyrgyz Republic	-0.0385	0.3333	0.4225			
Quarterly	Organisations	B2	Kazakhstan	0.0035	1.0000	0.9577			
Quarterly	Organisations	B2	Georgia	0.2464	0.0154	0.0141			
Quarterly	Organisations	B2	Armenia	0.1227	0.0294	0.0704			
Quarterly	Repositories	B1	Uzbekistan	0.4393	0.0375	0.0361			
Quarterly	Repositories	B1	Serbia	0.1471	0.2222	0.3373			
Quarterly	Repositories	B1	Kyrgyz Republic	0.2803	0.0645	0.0843			
Quarterly	Repositories	B1	Kazakhstan	0.1745	0.1250	0.2410			
Quarterly	Repositories	B1	Georgia	0.7141	0.0149	0.0120			
Quarterly	Repositories	B1	Armenia	0.2836	0.0857	0.0843			
Quarterly	Repositories	B2	Uzbekistan	-0.0067	0.9250	0.9277			
Quarterly	Repositories	B2	Serbia	0.0155	0.8519	0.8434			
Quarterly	Repositories	B2	Kyrgyz Republic	0.0366	0.6452	0.6988			
Quarterly	Repositories	B2	Kazakhstan	-0.0537	0.1875	0.5301			
Quarterly	Repositories	B2	Georgia	0.4938	0.0149	0.0120			
Quarterly	Repositories	B2	Armenia	0.2471	0.0286	0.0482			
Quarterly	Developer accounts	B1	Uzbekistan	-0.0211	0.7368	0.7619			
Quarterly	Developer accounts	B1	Serbia	0.0367	0.5429	0.6190			
Quarterly	Developer accounts	B1	Kyrgyz Republic	0.0597	0.3770	0.4524			
Quarterly	Developer accounts	B1	Kazakhstan	0.1028	0.1667	0.1786			
Quarterly	Developer accounts	B1	Georgia	0.2802	0.0189	0.0238			
Quarterly	Developer accounts	B1	Armenia	0.0550	0.3158	0.4881			
Quarterly	Developer accounts	B2	Uzbekistan	0.0181	0.5132	0.5595			
Quarterly	Developer accounts	B2	Serbia	0.0132	0.5571	0.6190			
Quarterly	Developer accounts	B2	Kyrgyz Republic	0.0398	0.1803	0.2857			
Quarterly	Developer accounts	B2	Kazakhstan	0.0380	0.2778	0.3095			
Quarterly	Developer accounts	B2	Georgia	0.1682	0.0189	0.0119			
Quarterly	Developer accounts	B2	Armenia	0.0748	0.0526	0.1071			

Note: B1: mean gap after 2022 minus the gap in the last pre-period (2021 or 2021Q4). B2: gap in the first post-period (2022 or 2022Q2) minus the same reference gap. In-space p: rank of |B| among the placebos (5×: pre-period MSPE at most five times that of the destination, all: all placebos). Main variant: annual 5×, quarterly all. In time (annual only): rank of the 2022 statistic among fictitious start years 2012–2019.

Table A9. Pooled effects and break statistics by inflow group

Frequency	Outcome	Group	Statistic	Value	p (5×)	p (all)	p, permutation (one-sided)	Splits
Annual	ICT exports (US$)	Georgia and Montenegro	B1	0.7373	0.0822	0.2509		
Annual	ICT exports (US$)	Georgia and Montenegro	B2	0.6643	0.0755	0.2486		
Annual	ICT exports	Georgia and	Mean gap	0.9603	0.0277	0.1397		

Frequency	Outcome	Group	Statistic	Value	p (5×)	p (all)	p, permutation (one-sided)	Splits
	(US$)	Montenegro						
Annual	ICT exports (US$)	GMA group	B1	0.6928	0.0593	0.2664		
Annual	ICT exports (US$)	GMA group	B2	0.5833	0.0802	0.2802		
Annual	ICT exports (US$)	GMA group	Mean gap	0.8257	0.0259	0.1228		
Annual	ICT exports (US$)	GMA minus KSUK	B1	-0.0113			0.6571	35
Annual	ICT exports (US$)	GMA minus KSUK	B2	-0.0152			0.5143	35
Annual	ICT exports (US$)	GMA minus KSUK	Mean gap	0.0379			0.4571	35
Annual	ICT exports (US$)	KSUK group	B1	0.7040	0.0643	0.2370		
Annual	ICT exports (US$)	KSUK group	B2	0.5985	0.0728	0.2515		
Annual	ICT exports (US$)	KSUK group	Mean gap	0.7879	0.0210	0.0950		
Annual	ICT exports (local currency)	Georgia and Montenegro	B1	0.5842	0.1869	0.3274		
Annual	ICT exports (local currency)	Georgia and Montenegro	B2	0.6392	0.1170	0.2323		
Annual	ICT exports (local currency)	Georgia and Montenegro	Mean gap	1.0033	0.0226	0.1190		
Annual	ICT exports (local currency)	GMA group	B1	0.5308	0.1317	0.3051		
Annual	ICT exports (local currency)	GMA group	B2	0.4980	0.1066	0.2799		
Annual	ICT exports (local currency)	GMA group	Mean gap	0.8887	0.0081	0.1065		
Annual	ICT exports (local currency)	GMA minus KSUK	B1	-0.3706			0.6857	35
Annual	ICT exports (local currency)	GMA minus KSUK	B2	-0.1072			0.6571	35
Annual	ICT exports (local currency)	GMA minus KSUK	Mean gap	-0.0192			0.6000	35
Annual	ICT exports (local currency)	KSUK group	B1	0.9015	0.0083	0.0830		
Annual	ICT exports (local currency)	KSUK group	B2	0.6052	0.0667	0.1878		
Annual	ICT exports (local currency)	KSUK group	Mean gap	0.9079	0.0028	0.0450		
Quarterly	Git pushes	Georgia and Montenegro	B1	0.8270	0.0001	0.0001		
Quarterly	Git pushes	Georgia and Montenegro	B2	0.6155	0.0001	0.0014		
Quarterly	Git pushes	Georgia and Montenegro	Mean gap	0.8028	0.0001	0.0014		
Quarterly	Git pushes	GMA group	B1	0.7282	0.0001	0.0001		
Quarterly	Git pushes	GMA group	B2	0.5691	0.0001	0.0002		
Quarterly	Git pushes	GMA group	Mean gap	0.7244	0.0001	0.0006		
Quarterly	Git pushes	GMA minus KSUK	B1	0.6878			0.0286	35
Quarterly	Git pushes	GMA minus KSUK	B2	0.5949			0.0286	35
Quarterly	Git pushes	GMA minus KSUK	Mean gap	0.6140			0.0286	35
Quarterly	Git pushes	KSUK group	B1	0.0404	0.7629	0.7610		
Quarterly	Git pushes	KSUK group	B2	-0.0258	0.8503	0.8497		
Quarterly	Git pushes	KSUK group	Mean gap	0.1104	0.4163	0.4628		
Quarterly	Organisations	Georgia and Montenegro	B1	0.5765	0.0001	0.0001		

Frequency	Outcome	Group	Statistic	Value	p (5×)	p (all)	p, permutation (one-sided)	Splits
Quarterly	Organisations	Georgia and Montenegro	B2	0.3017	0.0001	0.0001		
Quarterly	Organisations	Georgia and Montenegro	Mean gap	0.5660	0.0001	0.0001		
Quarterly	Organisations	GMA group	B1	0.4751	0.0001	0.0001		
Quarterly	Organisations	GMA group	B2	0.2420	0.0001	0.0001		
Quarterly	Organisations	GMA group	Mean gap	0.4713	0.0001	0.0001		
Quarterly	Organisations	GMA minus KSUK	B1	0.3251			0.0286	35
Quarterly	Organisations	GMA minus KSUK	B2	0.2367			0.0286	35
Quarterly	Organisations	GMA minus KSUK	Mean gap	0.3100			0.0286	35
Quarterly	Organisations	KSUK group	B1	0.1500	0.0022	0.0054		
Quarterly	Organisations	KSUK group	B2	0.0053	0.8301	0.8664		
Quarterly	Organisations	KSUK group	Mean gap	0.1613	0.0017	0.0094		
Quarterly	Repositories	Georgia and Montenegro	B1	0.6880	0.0001	0.0001		
Quarterly	Repositories	Georgia and Montenegro	B2	0.4565	0.0001	0.0001		
Quarterly	Repositories	Georgia and Montenegro	Mean gap	0.6905	0.0001	0.0001		
Quarterly	Repositories	GMA group	B1	0.5532	0.0001	0.0001		
Quarterly	Repositories	GMA group	B2	0.3867	0.0001	0.0001		
Quarterly	Repositories	GMA group	Mean gap	0.5566	0.0001	0.0001		
Quarterly	Repositories	GMA minus KSUK	B1	0.2929			0.0571	35
Quarterly	Repositories	GMA minus KSUK	B2	0.3888			0.0286	35
Quarterly	Repositories	GMA minus KSUK	Mean gap	0.2809			0.0571	35
Quarterly	Repositories	KSUK group	B1	0.2603	0.0009	0.0035		
Quarterly	Repositories	KSUK group	B2	-0.0021	0.9633	0.9681		
Quarterly	Repositories	KSUK group	Mean gap	0.2756	0.0006	0.0089		
Quarterly	Developer accounts	Georgia and Montenegro	B1	0.3104	0.0001	0.0251		
Quarterly	Developer accounts	Georgia and Montenegro	B2	0.1416	0.0001	0.0006		
Quarterly	Developer accounts	Georgia and Montenegro	Mean gap	0.3089	0.0001	0.0182		
Quarterly	Developer accounts	GMA group	B1	0.2253	0.0001	0.0355		
Quarterly	Developer accounts	GMA group	B2	0.1193	0.0001	0.0003		
Quarterly	Developer accounts	GMA group	Mean gap	0.2237	0.0001	0.0219		
Quarterly	Developer accounts	GMA minus KSUK	B1	0.1808			0.0857	35
Quarterly	Developer accounts	GMA minus KSUK	B2	0.0921			0.0286	35
Quarterly	Developer accounts	GMA minus KSUK	Mean gap	0.1735			0.0857	35
Quarterly	Developer accounts	KSUK group	B1	0.0445	0.2518	0.3672		
Quarterly	Developer accounts	KSUK group	B2	0.0273	0.1575	0.2793		
Quarterly	Developer accounts	KSUK group	Mean gap	0.0502	0.2150	0.3727		

Note: High: Georgia, Montenegro, Armenia. Low: Kazakhstan, Serbia, Kyrgyzstan, Uzbekistan. Mean gap: mean effect after 2022. B1 and B2 as in Table A8. Group p: pooled after Cavallo et al. (2013), 10,000 draws. 5× and all as in Table A8, main variant annual 5×, quarterly all. High − low: difference of group means, exact permutation over all splits of the economies (Splits), one-sided.

Table A10. In-time placebo with fictitious start in 2021Q1

Outcome	Destination or group	Mean gap 2021	Pre-period RMSPE	Exact pre-fit	p (all)	Placebos (all)	p (5×)	p, permutation (one-sided)	Splits
Git pushes	GMA group	0.0642			0.5649		0.5411		
Git pushes	KSUK group	0.0762			0.4358		0.3983		

Outcome	Destination or group	Mean gap 2021	Pre-period RMSPE	Exact pre-fit	p (all)	Placebos (all)	p (5×)	p, permutation (one-sided)	Splits
Git pushes	GMA minus KSUK	-0.0120						0.5143	35
Git pushes	Armenia	0.1106	0.0762	0	0.5167	59	0.5000		
Git pushes	Georgia	0.1541	0.0000	1	0.4333	59	0.4167		
Git pushes	Kazakhstan	-0.0546	0.0000	1	0.8333	59	0.8750		
Git pushes	Kyrgyz Republic	0.0351	0.0494	0	0.9333	59	0.9298		
Git pushes	Serbia	-0.1694	0.0300	0	0.3667	59	0.3265		
Git pushes	Uzbekistan	0.4935	0.0000	1	0.0500	59	0.0526		
Organisations	GMA group	0.0391			0.4779		0.4605		
Organisations	KSUK group	0.0014			0.9832		0.9866		
Organisations	GMA minus KSUK	0.0377						0.1429	35
Organisations	Armenia	0.0375	0.0003	0	0.5915	70	0.5556		
Organisations	Georgia	0.0276	0.0021	0	0.7183	70	0.6731		
Organisations	Kazakhstan	-0.0515	0.0000	1	0.4930	70	0.2778		
Organisations	Kyrgyz Republic	0.0013	0.0023	0	1.0000	70	1.0000		
Organisations	Serbia	-0.0160	0.0000	1	0.8732	70	0.8182		
Organisations	Uzbekistan	0.0720	0.0031	0	0.2394	70	0.1864		
Repositories	GMA group	0.0363			0.5076		0.3219		
Repositories	KSUK group	0.0467			0.3609		0.1549		
Repositories	GMA minus KSUK	-0.0103						0.5714	35
Repositories	Armenia	0.0396	0.0000	1	0.5904	82	0.4286		
Repositories	Georgia	0.0542	0.0000	1	0.5060	82	0.3824		
Repositories	Kazakhstan	-0.0354	0.0000	1	0.6265	82	0.4865		
Repositories	Kyrgyz Republic	0.0744	0.0005	0	0.3614	82	0.2742		
Repositories	Serbia	-0.0073	0.0000	1	0.9518	82	0.9286		
Repositories	Uzbekistan	0.1549	0.0014	0	0.1084	82	0.0615		
Developer accounts	GMA group	-0.0068			0.8059		0.7848		
Developer accounts	KSUK group	0.0097			0.7079		0.8030		
Developer accounts	GMA minus KSUK	-0.0165						0.8286	35
Developer accounts	Armenia	0.0092	0.0000	1	0.7976	83	0.9286		
Developer accounts	Georgia	-0.0251	0.0000	1	0.5000	83	0.5313		
Developer accounts	Kazakhstan	-0.0195	0.0000	1	0.5357	83	0.6071		
Developer accounts	Kyrgyz Republic	-0.0037	0.0000	1	0.9405	83	1.0000		
Developer accounts	Serbia	0.0114	0.0046	0	0.7381	83	0.7105		
Developer accounts	Uzbekistan	0.0505	0.0000	1	0.2619	83	0.2000		

Note: Synth fitted on 2020Q1–2020Q4, value: mean gap 2021Q1–2021Q4, before the 2022 shock. Country p: rank of the absolute mean gap among in-space placebos with the same fictitious start (all: main, 5× as in Table A8). Pooled and group p: Cavallo et al. (2013), 10,000 draws. High − low: exact permutation, one-sided. Exact pre-fit: pre-period RMSPE below 1e-6. With four pre-period quarters many placebos are fitted exactly, so the test has limited power.

Table A11. Developer inflow (Wachs 2022) and estimated effects

Code	Inflow (% of 2021 developers)	Inflow (developers)	Developers 2021	ICT exports (US$)	ICT exports (local currency)	Git pushes	Organisations	Repositories	Developer accounts
Georgia	93.8889	169	180	1.4097	1.6104	0.7152	0.4118	0.7199	0.2829
Montenegro	72.9167	35	48	0.5109	0.3962	0.8904	0.7202	0.6611	0.3349
Armenia	41.6309	97	233	0.5567	0.6596	0.5677	0.2818	0.2887	0.0533
Kazakhstan	12.7226	50	393	0.7035	0.8533	0.1296	0.1967	0.1755	0.0896
Serbia	8.2896	79	953	0.4522	0.7159	0.1880	0.1565	0.0518	0.0392
Uzbekistan	8.1081	15	185	0.7868	0.2668	0.1855	0.2090	0.5890	0.0114
Kyrgyz Republic	7.2000	9	125	1.2089	1.7958	-0.0614	0.0827	0.2863	0.0605

Note: Wachs (2022, Table 3): estimated active GitHub developers in 2021, inflow of Russian and Belarusian developers (heads) and inflow in % of 2021 developers. Effects: mean synth gaps in log points, 2022–2024 for exports and 2022Q2–2025Q4 for the GitHub outcomes. Wachs counts relocated developers, the synth effects measure activity.

Table A12. Rank agreement between developer inflow and estimated effects

Outcome	Inflow measure	N	Spearman rho	p (one-sided)	Orderings	Match test: difference	Match test: p (one-sided)	Match test: splits
ICT exports (US$)	Heads	7	-0.0714	0.5802	5040			
ICT exports (local currency)	Heads	7	0.1071	0.4198	5040			
Git pushes	Heads	7	0.5714	0.1000	5040			
Organisations	Heads	7	0.4286	0.1768	5040			
Repositories	Heads	7	0.1786	0.3565	5040			
Developer accounts	Heads	7	0.1786	0.3565	5040			
ICT exports (US$)	Share	7	-0.0357	0.5468	5040	0.0379	0.4571	35
ICT exports (local currency)	Share	7	-0.0714	0.5802	5040	-0.0192	0.6000	35
Git pushes	Share	7	0.8571	0.0119	5040	0.6140	0.0286	35
Organisations	Share	7	0.8571	0.0119	5040	0.3100	0.0286	35
Repositories	Share	7	0.6071	0.0833	5040	0.2809	0.0571	35
Developer accounts	Share	7	0.6786	0.0548	5040	0.1735	0.0857	35

Note: Spearman rank correlation between the Wachs (2022) inflow (share of 2021 developers or heads) and the synth effect over n economies. p: exact permutation over all n! orderings, one-sided. Match test: mean effect of the three economies with the largest shares minus the rest, exact permutation over all splits. The smallest attainable p is 1/35.

Table A13. International collaboration, effects by destination

Outcome	Destination	Mean 2021	Mean 2022Q2–2025Q4	Effect	Pre-period RMSPE	p (all)	Placebos (all)	p (5×)
Collaboration intensity (log, per account)	Armenia	-2.2260	-1.3490	1.3249	0.0964	0.0233	42	0.0313
Collaboration intensity (log, per account)	Georgia	-2.2409	-1.0778	1.3686	0.0827	0.0233	42	0.0323
Collaboration intensity (log, per account)	Kyrgyz Republic	-3.4364	-2.7321	0.3292	0.3673	0.3488	42	0.3488
Collaboration intensity (log, per account)	Kazakhstan	-3.7156	-2.9911	0.1639	0.3683	0.4884	42	0.4884
Collaboration intensity (log, per account)	Montenegro	-1.7755	-0.6944	1.3324	0.1707	0.0233	42	0.0263
Collaboration intensity (log, per account)	Serbia	-1.6897	-1.2487	0.5672	0.0209	0.0698	42	0.0909
Collaboration intensity (log, per account)	Uzbekistan	-4.0591	-3.3149	-0.1934	0.9361	0.4651	42	0.4651
Partner	Armenia	10.2500	29.8667	18.3915	1.0852	0.0233	42	0.0244

Outcome	Destination	Mean 2021	Mean 2022Q2–2025Q4	Effect	Pre-period RMSPE	p (all)	Placebos (all)	p (5×)
economies (number)								
Partner economies (number)	Georgia	11.7500	40.9333	28.4983	1.6794	0.0233	42	0.0238
Partner economies (number)	Kyrgyz Republic	4.2500	11.7333	4.6943	0.6929	0.0930	42	0.0732
Partner economies (number)	Kazakhstan	8.0000	23.9333	11.7813	1.3210	0.0465	42	0.0238
Partner economies (number)	Montenegro	5.5000	17.9333	10.1685	0.6242	0.0465	42	0.0263
Partner economies (number)	Serbia	29.2500	48.0000	14.1291	1.7728	0.0465	42	0.0238
Partner economies (number)	Uzbekistan	6.7500	13.9333	5.8523	0.7172	0.0930	42	0.0732

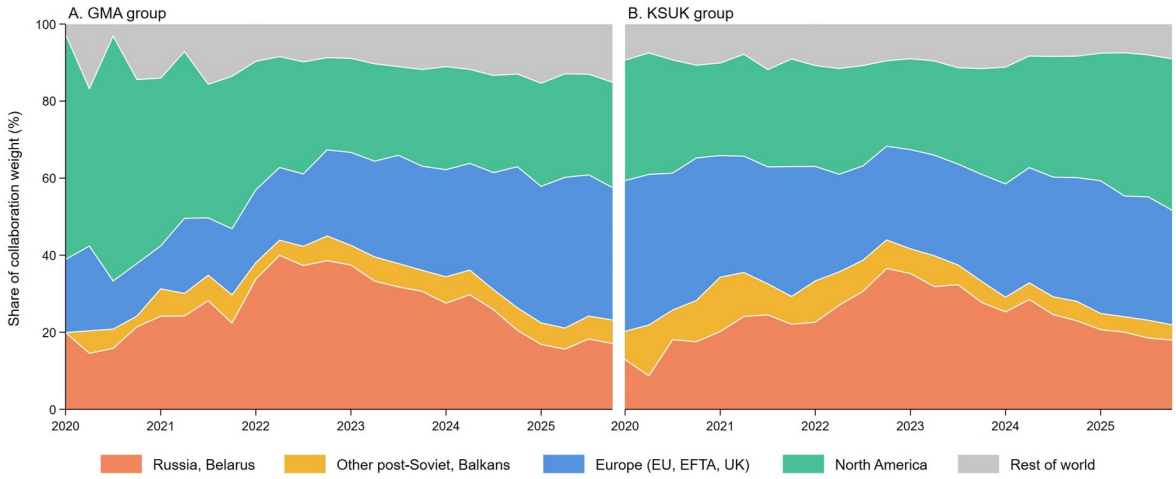
Note: Effect: mean gap 2022Q2–2025Q4. Means: actual means for 2021 and 2022Q2–2025Q4. p (all): rank of the absolute mean gap among all in-space placebos. p (5×): placebos with pre-period MSPE at most five times that of the destination.

Table A14. Collaboration by partner region, pooled effects

Partners	Economies	Window	Effect	Effect (%)	p	Donors
West (EU, EFTA, UK, US, CA)	GMA group	2022Q2-2025Q4	1.4925	344.8415	0.0001	39
West (EU, EFTA, UK, US, CA)	GMA group	2022Q2-2023Q3	1.5732	382.2063	0.0001	39
West (EU, EFTA, UK, US, CA)	GMA group	2024Q1-2025Q4	1.4630	331.8718	0.0001	39
West (EU, EFTA, UK, US, CA)	KSUK group	2022Q2-2025Q4	0.5847	79.4496	0.0001	39
West (EU, EFTA, UK, US, CA)	KSUK group	2022Q2-2023Q3	0.6078	83.6362	0.0001	39
West (EU, EFTA, UK, US, CA)	KSUK group	2024Q1-2025Q4	0.5965	81.5688	0.0009	39
Rest of world	GMA group	2022Q2-2025Q4	1.1428	213.5388	0.0032	28
Rest of world	GMA group	2022Q2-2023Q3	1.0107	174.7500	0.0034	28
Rest of world	GMA group	2024Q1-2025Q4	1.2159	237.3269	0.0047	28
Rest of world	Kazakhstan, Serbia	2022Q2-2025Q4	0.1354	14.4982	0.5835	28
Rest of world	Kazakhstan, Serbia	2022Q2-2023Q3	0.0089	0.8976	0.9777	28
Rest of world	Kazakhstan, Serbia	2024Q1-2025Q4	0.2470	28.0203	0.4144	28

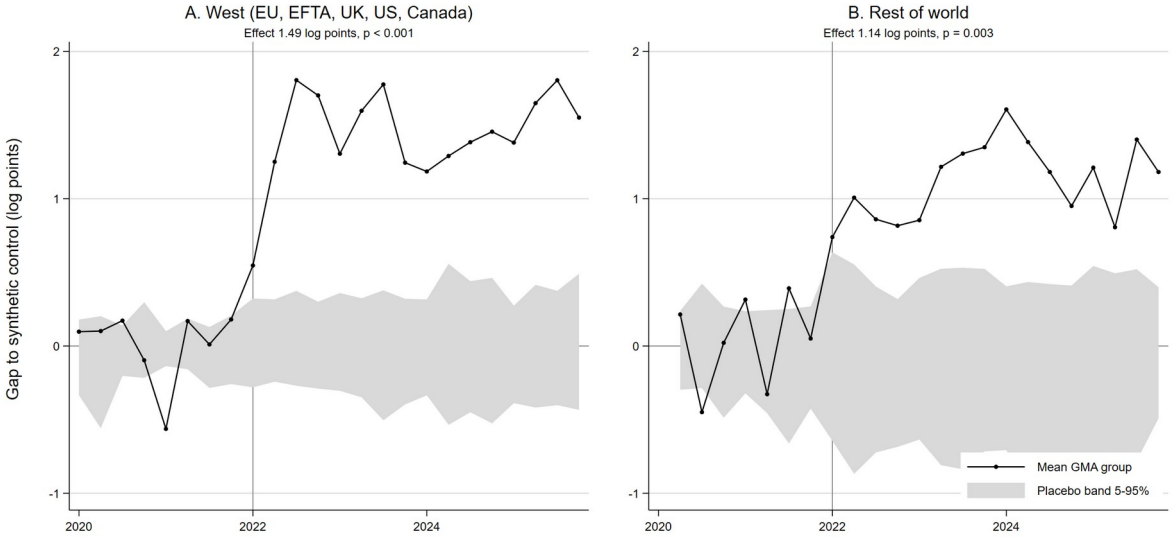
Note: Pooled synth effects on collaboration intensity with each partner region (log collaboration weight per developer account). p: Cavallo et al. (2013), 10,000 draws, all placebos. Partners exclude the eleven economies in Wachs (2022, Table 3). Pre-period 2020Q1–2021Q4, 2022Q1 excluded.

Figure A2. Shares of collaboration weight by partner region, quarterly



Note: Links within each group are excluded.

Figure A3. Pooled synth gap in collaboration intensity by partner region, GMA group



Note: Shaded area: 5 to 95 % placebo band.

Table A15. Armenia before and after the Nagorno-Karabakh inflow

Outcome	Destination	Gap 2023Q4–2025Q4	Gap 2022Q2–2023Q3	Change
Git pushes	Armenia	0.4678	0.7175	-0.2497
Git pushes	Georgia	0.6226	0.8540	-0.2314
Git pushes	Montenegro	0.8310	0.9795	-0.1485
Organisations	Armenia	0.3023	0.2512	0.0511
Organisations	Georgia	0.4369	0.3740	0.0629
Organisations	Montenegro	0.7838	0.6248	0.1590
Repositories	Armenia	0.2614	0.3295	-0.0681
Repositories	Georgia	0.7283	0.7073	0.0210
Repositories	Montenegro	0.6584	0.6651	-0.0067
Developer accounts	Armenia	0.0191	0.1046	-0.0855
Developer accounts	Georgia	0.2859	0.2784	0.0074
Developer accounts	Montenegro	0.3725	0.2784	0.0942

Note: Mean synth gap in log points before and after the arrival of refugees from Nagorno-Karabakh in Armenia in late September 2023. Georgia and Montenegro for comparison. Descriptive.

Table A16. Robustness to the short pre-period, GitHub outcomes, GMA group

Outcome	Estimator	Economies	Effect	Effect (%)	p	Placebos or donors	Exact pre-fit	Pre-period RMSPE
Git pushes	Synth, 8 lags (main)	GMA group	0.7244	106.3507	0.0006	59	5	0.0478
Git pushes	Synth, 8 lags (main)	GE	0.7152	104.4531				0.0130
Git pushes	Synth, 8 lags (main)	ME	0.8904	143.6068				0.0617
Git pushes	Synth, 8 lags (main)	AM	0.5677	76.4146				0.0687
Git pushes	Synth, 2 means	GMA group	0.6275	87.3005	0.0021	59	0	0.1072
Git pushes	Synth, 2 means	GE	0.7892	120.1561				0.0674
Git pushes	Synth, 2 means	ME	0.8132	125.5022				0.1211
Git pushes	Synth, 2 means	AM	0.2803	32.3536				0.1331
Organisations	Synth, 8 lags (main)	GMA group	0.4713	60.2033	0.0001	70	6	0.0113
Organisations	Synth, 8 lags (main)	GE	0.4118	50.9488				0.0107
Organisations	Synth, 8 lags (main)	ME	0.7202	105.4866				0.0212
Organisations	Synth, 8 lags (main)	AM	0.2818	32.5567				0.0019
Organisations	Synth, 2 means	GMA group	0.4321	54.0453	0.0001	70	0	0.0163
Organisations	Synth, 2 means	GE	0.4154	51.4968				0.0152
Organisations	Synth, 2 means	ME	0.6705	95.5131				0.0265
Organisations	Synth, 2 means	AM	0.2104	23.4144				0.0071
Repositories	Synth, 8 lags (main)	GMA group	0.5566	74.4644	0.0001	82	27	0.0089
Repositories	Synth, 8 lags (main)	GE	0.7199	105.4216				0.0068
Repositories	Synth, 8 lags (main)	ME	0.6611	93.6919				0.0190
Repositories	Synth, 8 lags (main)	AM	0.2887	33.4636				0.0009
Repositories	Synth, 2 means	GMA group	0.5921	80.7818	0.0001	82	0	0.0218
Repositories	Synth, 2 means	GE	0.6930	99.9638				0.0248
Repositories	Synth, 2 means	ME	0.7287	107.2342				0.0289
Repositories	Synth, 2 means	AM	0.3547	42.5776				0.0116
Developer accounts	Synth, 8 lags (main)	GMA group	0.2237	25.0670	0.0219	83	18	0.0038
Developer accounts	Synth, 8 lags (main)	GE	0.2829	32.6970				0.0022
Developer accounts	Synth, 8 lags (main)	ME	0.3349	39.7754				0.0083
Developer accounts	Synth, 8 lags (main)	AM	0.0533	5.4718				0.0009
Developer accounts	Synth, 2 means	GMA group	0.1696	18.4880	0.0609	83	0	0.0100
Developer accounts	Synth, 2 means	GE	0.1860	20.4396				0.0087
Developer accounts	Synth, 2 means	ME	0.2642	30.2399				0.0177
Developer accounts	Synth, 2 means	AM	0.0587	6.0498				0.0037
Collaboration intensity	Synth, 8 lags (main)	GMA group	1.3420	282.6614	0.0001	42	3	0.1166
Collaboration intensity	Synth, 8 lags (main)	GE	1.3686	292.9878				0.0827
Collaboration	Synth, 8 lags	ME	1.3324	279.0284				0.1707

Outcome	Estimator	Economies	Effect	Effect (%)	p	Placebos or donors	Exact pre-fit	Pre-period RMSPE
intensity	(main)							
Collaboration intensity	Synth, 8 lags (main)	AM	1.3249	276.1778				0.0964
Collaboration intensity	Synth, 2 means	GMA group	1.3270	276.9691	0.0001	42	0	0.2453
Collaboration intensity	Synth, 2 means	GE	1.4093	309.3226				0.2151
Collaboration intensity	Synth, 2 means	ME	1.3129	271.7055				0.2311
Collaboration intensity	Synth, 2 means	AM	1.2587	252.0890				0.2897
Git pushes	SDID	GMA group	0.5608	75.2048	0.0045	59		
Git pushes	SDID	GE	0.5807	78.7353		59		
Git pushes	SDID	ME	0.8696	138.5960		59		
Git pushes	SDID	AM	0.2030	22.5092		59		
Git pushes	DiD	GMA group	0.4654	59.2625	0.0538	59		
Git pushes	DiD	GE	0.7298	107.4671		59		
Git pushes	DiD	ME	0.5705	76.9238		59		
Git pushes	DiD	AM	0.0958	10.0539		59		
Organisations	SDID	GMA group	0.4421	55.6016	0.0000	70		
Organisations	SDID	GE	0.3747	45.4627		70		
Organisations	SDID	ME	0.7518	112.0827		70		
Organisations	SDID	AM	0.2117	23.5742		70		
Organisations	DiD	GMA group	0.4230	52.6605	0.0000	70		
Organisations	DiD	GE	0.3290	38.9596		70		
Organisations	DiD	ME	0.6703	95.4804		70		
Organisations	DiD	AM	0.2698	30.9749		70		
Repositories	SDID	GMA group	0.4608	58.5366	0.0000	82		
Repositories	SDID	GE	0.5641	75.7896		82		
Repositories	SDID	ME	0.6067	83.4324		82		
Repositories	SDID	AM	0.2173	24.2722		82		
Repositories	DiD	GMA group	0.3961	48.5962	0.0262	82		
Repositories	DiD	GE	0.7036	102.0979		82		
Repositories	DiD	ME	0.4361	54.6741		82		
Repositories	DiD	AM	0.0485	4.9648		82		
Developer accounts	SDID	GMA group	0.1599	17.3433	0.1295	83		
Developer accounts	SDID	GE	0.2225	24.9162		83		
Developer accounts	SDID	ME	0.2473	28.0578		83		
Developer accounts	SDID	AM	0.0178	1.7965		83		
Developer accounts	DiD	GMA group	0.0824	8.5909	0.4495	83		
Developer accounts	DiD	GE	0.1875	20.6217		83		
Developer accounts	DiD	ME	0.1345	14.3937		83		
Developer accounts	DiD	AM	-0.0747	-7.1990		83		
Collaboration intensity	SDID	GMA group	1.2704	256.2288	0.0000	42		
Collaboration intensity	SDID	GE	1.3301	278.1418		42		
Collaboration intensity	SDID	ME	1.3526	286.7580		42		
Collaboration intensity	SDID	AM	1.0801	194.5012		42		
Collaboration intensity	DiD	GMA group	1.2769	258.5350	0.0000	42		
Collaboration intensity	DiD	GE	1.4006	305.7784		42		
Collaboration intensity	DiD	ME	1.1545	217.2513		42		
Collaboration intensity	DiD	AM	1.2754	258.0158		42		

Note: GMA group, effects in log points over 2022Q2–2025Q4. Synth, 8 lags: main specification. Synth, 2 means: outcome means of 2020 and 2021 as the only predictors. Pooled p after Cavallo et al. (2013) with all placebos. J: placebos or donors. Exact pre-fit: placebos with pre-period RMSPE below 1e-6. SDID: synthetic difference in differences (Arkhangelsky et al. 2021). DiD: the same without unit and time weights. SDID and DiD p from 500 placebo replications.

Table A17. Serbia: trade in ICT services with Russia

Reporter	Flow	2019	2021	2022	2023	2024	2025 (prel.)	Share of Russia 2021 (%)	Share of Russia 2024 (%)
Serbia	Exports to Russia	11	5	20	24	255	224	0.3	6.2
Serbia	Imports from Russia	11	4	27	38	27	33	0.7	3.0

Note: Telecommunications, computer and information services (BPM6 item SI), million EUR, as reported by Serbia to Eurostat. Share: Russia in % of Serbia’s trade with all partners in the same flow. Missing: confidential or not published. 2025 preliminary.

Table A18. Kazakhstan: trade in computer services by partner, million US dollars

	2021	2022	2023	2024	2025
Exports, total	60.1	337.0	529.1	840.4	1,142.7
Exports, no partner country	36.6	258.5	343.1	729.5	1,064.5
Exports, Russia	3.4	5.8	41.2	44.8	
Exports, Cyprus and United Arab Emirates	2.8	26.2	55.2	7.6	12.8
Imports, total	233.3	364.8	492.8	336.5	429.1
Imports, no partner country	75.7	76.2	191.9	98.4	46.9
Imports, Russia	58.9	85.3	67.6	58.9	101.5
Imports, Cyprus and United Arab Emirates	8.4	4.4	54.8	37.6	29.4
Exports, no partner country (% of total)	60.9	76.7	64.8	86.8	93.2

Note: Computer services (EBOPS 2010 item 9.2), million US dollars, National Bank of Kazakhstan, latest release for each year. No partner country: the National Bank’s residual item Other. Missing: not published.

Table A19. ICT service exports of the GMA group through 2025

Specification	Economies	Donors	Effect	p (5×)	p (all)
Main donor pool, 2022–2024	GMA group	52	0.826	0.026	0.123
Donors reporting 2025, 2022–2024	GMA group	21	0.869	0.005	0.171
Donors reporting 2025, 2022–2025	GMA group	21	0.902	0.014	0.181
Donors reporting 2025, 2025 only	GMA group	21	1.001	0.078	0.247
Gap in 2025, log points	Georgia	21	1.864		
Export gain in 2025, million US dollars	Georgia	21	1,092		
Gap in 2025, log points	Montenegro	21	0.192		
Export gain in 2025, million US dollars	Montenegro	21	34		
Gap in 2025, log points	Armenia	21	0.946		
Export gain in 2025, million US dollars	Armenia	21	919		
Export gain in 2025, million US dollars	GMA group	21	2,044		

Note: Effects: mean synth gap in log points over the stated years. Pooled p after Cavallo et al. (2013), 10,000 draws, with placebos whose pre-period MSPE is at most five times that of the destination (5×) or all placebos. Donors reporting 2025: main donor pool restricted to donors with ICT service exports for 2025 in the WDI. 2025 deflated with the US CPI-U of the Bureau of Labor Statistics. Export gain: equation (5), current US dollars.