When Trade Returns but Relationships Do Not: Russian Grain after the Invasion of Ukraine

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Abstract

An export recovery need not restore the trading relationships that preceded it. Russian seaport grain throughput was 82 percent higher in 2024 than in 2021, yet importers with greater prewar Russian dependence shifted persistently away from Russian suppliers. Combining global customs data with port throughput and vessel records, we trace this adjustment through alternative suppliers and maritime networks. Across 204 destinations, ten percentage points greater prewar dependence is associated with a 2.35-point larger decline in Russia's sourcing share and a 2.07-point increase in the share of durable alternative suppliers. The corresponding estimates for 152 emerging market and developing economies are nearly identical. Route and vessel records document substantial physical rematching beneath the aggregate recovery. A conditional sourcing model accommodates expanding Russian supply alongside destination reallocation; equalizing its implied Russian-access component largely removes the sourcing gradients. The findings distinguish resilience of aggregate shipments from continuity of bilateral access, without equating either with household welfare or identifying a primitive sanctions cost.

Keywords: geopolitical fragmentation; emerging economies; grain trade; supplier relationships; maritime networks.

JEL classifications: F14, F15, L91, Q17.

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1. Introduction

Trade can recover without restoring the relationships that made it possible. Research on geopolitical fragmentation documents the separation of trading blocs and the emergence of countries that connect them, but aggregate flows leave an important question unresolved: when a disrupted exporter recovers, do its established buyers recover with it? For economies dependent on imported staples, the distinction is consequential. A plentiful world market is not the same as an unchanged procurement network. This paper examines that distinction in Russian grain after the invasion of Ukraine, asking how recovered shipments coexist with persistent reallocation away from historically dependent importers.

Russian grain provides an unusually revealing setting because physical supply and the organization of trade need not move together. The February 2022 invasion directly disrupted Ukrainian production and maritime access, while the wider sanctions environment affected transactions involving Russian counterparties. Food-related exemptions meant that Russian grain was not subject to a general U.S. or EU commodity embargo. We combine annual destination–origin–product customs records, independent Russian seaport grain throughput, Kpler candidate-route observations, and S&P port calls. The global benchmark covers 204 destinations; a separately defined sample of 152 emerging market and developing economies establishes the relevance of the results to this group rather than assuming it from the global averages.

The first finding is that aggregate recovery and bilateral disengagement occurred together. Russian seaport grain throughput rose from 35.0 million tonnes in 2021 to 63.6 million in 2024. Nevertheless, ten percentage points greater Russian dependence in 2017–2018 is associated with a 2.35-percentage-point larger post-2021 decline in Russia's share of destination grain imports. This is a comparison between destinations, not a statement that Russian exports fell or that every buyer imported less. The corresponding estimate within the emerging market and developing economy sample is also −2.35 points.

The second finding is that substitution draws heavily on relationships established before the disruption. In the global sample, the same exposure difference is associated with a 2.52-point rise in sourcing outside Russia and Ukraine, of which 2.07 points comes from origins that supplied the destination in each of 2017, 2018, and 2019. The estimates for emerging market and developing economies are 2.45 and 2.09 points, respectively. Durable supplier relationships thus account for much of the compositional response. This pattern supports an interpretation of established commercial connections as adjustment capacity, although it does not identify the causal return to acquiring an additional supplier before a crisis.

The third finding is that recovered shipments rest on substantial physical rematching. Customs-link accounting documents offsetting gains and losses across relationships. Kpler route panels distinguish route activity from voyage frequency conditional on activity, while S&P records show that new routes offset exits and absorb transport distance and time. These observations connect changes in procurement to changes in the network that moves goods. They do not measure grain tonnage on every voyage or establish that longer operating time represents congestion.

The quantitative exercise asks how far unequal access can reconcile expanding supply with the observed sourcing gradients. A model with persistent supplier weights and a fixed prewar feasible network conditions on the Russian throughput path and allows a Russian transaction wedge to vary with predetermined destination dependence. The calibrated model reproduces the sign of the Russian and incumbent-supplier responses, although it understates incumbent substitution. Equalizing the destination component of the wedge largely removes both gradients. This is conditional allocation accounting: the model does not separately identify insurance, freight, payment, or compliance costs, and its expenditure and transport-resource comparisons are not welfare estimates.

The contribution to the fragmentation literature is to separate recovery of an origin total from restoration of access for its prior buyers. Gopinath et al. (2025) document reconfiguration across geopolitical blocs and the role of connector economies. We study a different margin: the persistence and replacement of procurement relationships within a staple commodity market whose disrupted exporter subsequently ships more. The emerging-economy results show that the distinction is empirically relevant within that group, without claiming that its response is uniquely larger than that of advanced economies. Evidence of bilateral disengagement is not evidence that trade has stopped; it is evidence that the organization of access has changed.

The contribution to the sanctions literature is to examine reallocation where the commodity itself is broadly exempt. Crozet and Hinz (2020) show that sanctions episodes can affect trade beyond directly targeted products, while Korovkin and Makarin (2023) document the disruption of intergroup trade during the earlier Russia–Ukraine conflict. Fisman, Marcolongo, and Wu (2025) demonstrate how rerouting undermined the blockade of Donbas and altered intermediaries' rents. Our setting concerns neither the same blockade nor an identified rent transfer: it shows that legal exemptions and recovered shipment totals can coexist with a changed destination network. The contrast directs attention to transactions and relationships without attributing every change to sanctions.

The contribution to network and transportation research is to connect the replacement of suppliers with the replacement of physical routes. Chaney (2014) and Bernard, Moxnes, and Saito (2019) emphasize the importance of commercial networks; Carvalho et al. (2021) show how disruptions propagate through production linkages. Brancaccio, Kalouptsidi, and Papageorgiou (2020) demonstrate that transport costs and shipping allocations are endogenous to trade. We bring supplier histories and vessel operations to the same empirical episode. The linkage is triangulation across distinct measurement systems, not a claim that a port call is an observed grain shipment or that the shipping evidence identifies our model parameter.

The remainder of the paper follows the adjustment from commodities to relationships and then to allocation. Section 2 describes the institutional setting. Section 3 presents the data and scope, and Section 4 defines the empirical comparisons. Sections 5 and 6 report procurement and maritime-network results. Section 7 develops the conditional sourcing model; Section 8 presents the common-access counterfactual. Section 9 concludes.

2. An Exempt Commodity in a Disrupted Trading System

The institutional setting makes a uniform Russian grain-supply collapse an inappropriate organizing assumption. Ukraine faced direct military destruction and maritime blockade; Russian transactions faced a changing financial, legal, and logistical environment, but food-related trade enjoyed important exemptions. Russian seaport grain shipments subsequently expanded. The empirical question is therefore how destinations adjusted to the combined disruption, conditional on their distinct prior reliance on Russia and Ukraine, rather than whether a blanket grain embargo eliminated Russian exports.

Food exemptions limited the direct reach of sanctions without guaranteeing frictionless execution. U.S. Treasury guidance clarified food- and fertilizer-related authorizations in 2022, and UNCTAD (2022) described the broader disruption to maritime logistics. A transaction can remain legally permitted while its bank, carrier, insurer, or counterparty changes the terms on which it is willing to participate. These channels motivate a destination-access interpretation, but neither their existence nor the exemptions identify the magnitude of a bilateral cost wedge. The evidence below distinguishes that interpretation from directly measured charges.

Ukraine's disruption enters the design separately because its exposure overlaps with Russian dependence. The Black Sea Grain Initiative reopened a monitored export channel in 2022 before ending in July 2023 (United Nations 2023). Buyers previously sourcing from both countries could respond to both disruptions. Including Ukrainian exposure and its year interactions avoids mechanically treating correlated Ukrainian reliance as Russian reliance; it does not guarantee that all common regional or destination-specific confounding has been removed.

The aggregate throughput series establishes the recovery that the destination evidence must be able to accommodate. PORTSTAT records 36.2 million tonnes in 2022, 57.1 million in 2023, and 63.6 million in 2024, against 35.0 million in 2021. These are seaport grain export-throughput observations, not a census of all Russian exports by every mode and not an estimate of installed production capacity. They make persistent scarcity at the Russian national port-total level an insufficient explanation for all subsequent destination responses.

3. Data, Measurement, and Emerging-Economy Scope

The data distinguish four objects that are often conflated: grain purchases, aggregate port tonnage, route activity, and transport-resource use. Customs data identify sourcing relationships; PORTSTAT anchors Russia's seaport grain total; Kpler and S&P describe maritime operations with different coverage and observation units. We retain those distinctions throughout. The main sourcing regressions use 2019–2024 observations and exposures fixed in 2017–2018, while longer histories establish relationships and shorter matched panels locate maritime adjustment.

The procurement panel is built from CEPII's BACI HS17 bilateral trade records for cereals in HS headings 1001–1008. BACI reconciles bilateral reporting rather than treating one country's export declarations as a complete record (Gaulier and Zignago 2010). Annual values are aggregated to destination–origin and destination totals, retaining the product detail for link accounting and the model. The global analysis conditions on the supported destination universe with prewar exposures and a 2021 income classification, excluding Russia and Ukraine as import destinations. The three share regressions contain 1,223 destination-year observations across 204 destinations. They are equally weighted destination comparisons rather than world-value-weighted export regressions.

Supplier histories classify relationships before the invasion and at the origin–destination level. A core incumbent is an origin other than Russia or Ukraine with positive cereal trade to the destination in every year from 2017 through 2019. Its outcome is the share of the destination's current cereal-import value supplied by such origins. This is a durable country-pair supplier classification, not a requirement that every HS6 product be traded in each prewar year. Other-source share includes all origins outside Russia and Ukraine, so the core-incumbent outcome is a subset of it.

Missing observations are distinguished from measured absence within an observed trade universe. A missing destination-year is not assigned zero imports. Absent links can be counted as zero within a supported reporting and product universe for explicit entry–exit accounting, whereas invalid or unreported quantities remain missing. Quantity aggregates are retained only where positive reported quantities cover at least 90 percent of import value. This is particularly important for comparing annual and monthly records, where the identity of reporting destinations changes.

The emerging-economy sample uses a classification published before the war rather than one selected from the results. We transcribe the 156 emerging market and developing economies in Table E of the IMF's April 2021 World Economic Outlook and intersect them with the unchanged analysis sample. This yields 152 destinations and 912 observations. The label includes developing and frontier economies as well as emerging markets; it is not a financial-index investability classification. We also report a World Bank 2021 low- and middle-income subset as a distinct sensitivity exercise. Neither classification is changed after observing coefficients.

The maritime sources measure operations rather than a common cargo census. Kpler supplies candidate port-to-port paths, route activity, voyage counts, and vessel characteristics; grain-terminal names identify a candidate-grain subset rather than verified cargo on each path. S&P's purchased 2020–2025 port-call data supply Russia-origin foreign legs, distances, sequence-based sea time, and vessel histories. We emphasize 2020–2024 when aligning it with the paper and treat any displayed 2025 observation as supplementary. No S&P result is assigned a 2019 pre-period that the data do not contain.

The model retains the destination scope but uses a narrower, explicitly supported product environment. Its 22 HS6 products have the baseline relationships and origin–product quantity inputs needed by the solver. Observed shares are rebuilt on those products before comparison with model predictions. Consequently,

the model-fit data coefficients are not numerically identical to the all-cereal event-study coefficients. This restriction is a measurement bridge, not a second estimate of the same sample; Table 4 states it explicitly.

[Table 1 is about here]

[Table 2 is about here]

4. Empirical Strategy

The empirical strategy estimates how sourcing changes differ with prewar Russian dependence while allowing a separate Ukrainian exposure path. It is a continuous-exposure event study on a common shock date, not a comparison of legally sanctioned and unsanctioned grain shipments. A causal interpretation requires the exposure gradient to have evolved similarly absent the disruption. We therefore distinguish post-period associations, pre-period diagnostics, and conditional counterfactuals rather than presenting each as a separately identified causal effect.

Exposure is measured early enough to leave an observed pre-event interval. Let E_d^R and E_d^U be the destination's mean annual Russian and Ukrainian shares in 2017–2018, expressed as fractions, and define $x_d^R = 10E_d^R$ and $x_d^U = 10E_d^U$. With outcome shares in percentage points, a one-unit increase in either regressor means ten percentage points greater dependence. The dynamic specification is

$$y_{dt} = \alpha_d + \lambda_t + \sum_{\ell \neq 2021} (\gamma_\ell^R x_d^R + \gamma_\ell^U x_d^U)\mathbf{1}\{t = \ell\} + u_{dt}. \quad (1)$$

Destination fixed effects absorb persistent differences between importers, while year fixed effects absorb shocks common across them. The omitted year is 2021; the plotted zero in that year is a normalization, not an estimated zero effect. Standard errors are clustered by destination and plotted intervals are pointwise 95 percent intervals. A pooled specification summarizes the post-2021 exposure gradient:

$$y_{dt} = \alpha_d + \lambda_t + \beta_R x_d^R Post_t + \beta_U x_d^U Post_t + u_{dt}. \quad (2)$$

The pooled coefficient and the year-specific paths answer related but different questions. Equation (2) compares average pre- and post-period outcomes, whereas equation (1) measures each year's difference relative to 2021. Neither is an aggregate export-growth rate. Source shares also sum mechanically across mutually exclusive origin groups; the core-incumbent share is nested in other sources. A similar-sized increase and decrease in these outcomes is therefore not independent proof of restored tonnage or expenditure.

Parallel-trend diagnostics are reported outcome by outcome rather than converted into a universal endorsement of the design. Joint tests of the 2019 and 2020 Russian interactions do not reject for Russian or core-incumbent shares, but reject for the broad other-source share. Non-rejection is not proof of parallel trends, and two pre-event coefficients provide limited information about plausible deviations. Rambachan and Roth (2023) explain why sensitivity to departures matters beyond a preliminary significance test. We do not infer that a pretrend opposing the post coefficient automatically strengthens causal identification.

The emerging-economy extension changes only sample membership, not the specification or outcome definitions. We report all three outcomes, the complete event paths, and the joint pre-period tests, then add a pooled specification with Russian- and Ukrainian-exposure-specific linear trends. Those trends are estimated jointly over the full period and are not claimed to be extrapolations estimated solely before the war. A separate World Bank classification checks scope sensitivity. These exercises establish relevance within emerging and developing economies; they do not test whether their coefficients differ statistically from advanced economies.

The maritime comparisons distinguish extensive activity from conditional intensity. Kpler candidate routes are matched using pre-2022 information and estimated with route and destination-by-period fixed effects, clustering by destination. The activity outcome retains supported route-period zeros. Natural-log voyage frequency uses only positive counts, so its sample changes with activity; it is not an effect on an identified always-active principal stratum. A separate annual comparison and vessel-size decomposition are reported in Figures A3 and A4.

Accounting identities describe the scale of network replacement without imposing a counterfactual. For a link-level additive outcome z, define continuing links C_t, links active in 2021 but absent in year t, X_t, and links active in t but absent in 2021, N_t. Then

$$Z_t - Z_{2021} = \sum_{r \in C_t} (z_{rt} - z_{r,2021}) - \sum_{r \in X_t} z_{r,2021} + \sum_{r \in N_t} z_{rt}. \quad (3)$$

The identity applies separately to observed trade values, foreign legs, leg-kilometers, and sea-days on their respective supports. A link called new relative to 2021 may have operated earlier; the label is not necessarily first-ever entry. Large gross components can offset in the net total. Their existence documents rematching but does not assign each component to the invasion or to sanctions.

5. Recovered Shipments, Replaced Suppliers

The sourcing evidence reveals a recovery organized around different relationships, including within emerging and developing economies. Russian seaport totals expand while historically dependent destinations reduce their Russian shares, and much of the offsetting source-share increase comes from durable alternatives. We first establish the global pattern, then show its scope and diagnostic limits. This ordering keeps the question of who buys from whom separate from whether total grain availability or consumption fell.

Figure 1 puts the aggregate and destination evidence on a common timeline. PORTSTAT throughput is 3.5 percent above 2021 in 2022, 63.4 percent above in 2023, and 81.9 percent above in 2024. In the all-cereal destination panel, the Russian-share exposure coefficient is negative in each post year: −2.97, −1.66, and −2.46 percentage points. The apparent contradiction disappears once the units are made explicit: a Russian port total can expand while the relative sourcing shares of particular buyers decline. These two measures do not by themselves identify the countries absorbing every additional Russian tonne.

[Figure 1 is about here]

The pooled Russian-share estimate is economically material without implying universal disengagement. Table 3 reports −2.345 points, with a destination-clustered standard error of 0.770. This means that a ten-point prewar exposure difference predicts a 2.35-point larger share decline after 2021, conditional on Ukrainian exposure. It does not mean that each destination loses this amount, that imports in levels fall everywhere, or that 2.35 percent of world grain trade disappears.

Alternative origins gain primarily through established supplier relationships. The other-source coefficient is 2.519 points (standard error 0.838), and the core-incumbent coefficient is 2.068 points (standard error 0.743). The ratio of these point estimates is about 82 percent. It is a descriptive comparison of two regression coefficients, not an estimated mediation share or a causal decomposition. Figure 2 shows the corresponding dynamics and makes the nested outcome definitions visible.

[Figure 2 is about here]

Emerging and developing economies display almost the same pooled reallocation pattern as the global sample. The IMF-defined subset yields coefficients of −2.346 for Russian share, 2.450 for other sources, and 2.085 for core incumbents, with standard errors of 0.816, 0.884, and 0.784. Table 3 reports these estimates alongside the global benchmark. The emerging-economy result is not a relabeling of global evidence, nor evidence of an exceptional emerging-economy treatment effect; it is a direct within-group replication of the same comparison.

[Table 3 is about here]

[Figure 3 is about here]

The diagnostic evidence is more favorable for Russian and core-incumbent shares than for the broad residual source category. Joint pre-period p-values are 0.385, 0.038, and 0.434 in the global sample, and 0.184, 0.014, and 0.235 in the emerging-economy sample, ordered as Russia, other sources, and core incumbents. The pooled emerging-economy estimates with exposure-specific linear trends remain negative for Russia and positive for both alternatives; the core estimate is 1.834 points with a standard error of 0.917. Table A1 reports these estimates and the World Bank scope check. We retain the broad other-source response as a compositional fact with a weaker causal interpretation, rather than hiding its pre-period behavior.

Trade-link accounting reveals gross turnover beneath the source-share changes. Figure 4 separates gains on new or reactivated links, losses on exited links, and changes on continuing links according to its stated support. These components document how buyers and sellers can reorganize without a common decline in all shipments. Accounting provides the bridge between aggregate recovery and bilateral reallocation, but cannot determine whether the same flows would have occurred without the war.

[Figure 4 is about here]

Total-import estimates are not sufficiently invariant to support a general shortage claim. The annual panel produces negative Russian-exposure coefficients for IHS import value and quantity, whereas stable-reporter monthly estimates under the earlier exposure definition are close to zero and imprecise. Figure A1 retains the annual event studies, and Table A2 reports the annual–monthly reporting-support diagnostic; Figure A2 separately presents monthly sourcing dynamics. Table A2 uses 2017–2019 exposure and therefore is not the same specification as the main sourcing estimates. Differences in reporting support, exposure measurement, and frequency mean neither result automatically invalidates the other; they do limit a claim about universal import contraction. We therefore do not infer hunger, mortality, or household welfare losses from the sourcing coefficients.

Political affinity offers a narrower, less stable account of marginal supplier matching than the main procurement result. Figure A5 reports link-activation comparisons in fixed candidate-supplier sets with relationship, destination–product–year, and origin–product–year fixed effects and interacted CEPII geography and network controls. Positive marginal-link estimates do not establish a corresponding value or quantity effect, and sensitivity to differential trends limits their interpretation. We do not conclude either that politics is irrelevant or that political blocs explain most supplier replacement.

6. The Physical Network Behind the Recovery

The maritime evidence shows that the procurement changes are accompanied by extensive operational reorganization. Kpler identifies the timing of route activity and conditional voyage-frequency changes, while S&P decomposes route replacement and transport resources. These sources corroborate the presence of a changing network, not a single precisely measured grain-transport mechanism. Their value lies in showing why a recovered aggregate can conceal a substantial rebuilding of trading arrangements.

Kpler's two margins separate a route's disappearance from a change in its use when active. Figure 5 places route activity above natural-log voyage frequency. The quarterly series show disruption around 2022 and subsequent adjustment, but some pre-event coefficients differ from the omitted quarter and later estimates are imprecise. This cautions against using the series as a clean standalone estimate of a sanctions effect. The relevant empirical content is the timing and distinction between activity and conditional use, interpreted alongside the matched-route checks.

[Figure 5 is about here]

The difference between PORTSTAT tonnes and Kpler candidate voyages is informative about measurement rather than evidence that one must be wrong. Tonnage can rise while observed paths fall if payloads, utilization, terminal composition, coverage, or routing change. Figure A6 sets the two series beside one another without treating candidate grain-terminal departures as a cargo census. Vessel-size evidence in Figure A4 likewise distinguishes within-route changes from the composition of routes; an aggregate mean need not move in the direction of its matched-route component.

S&P records show large offsetting gains and losses when the 2021 route set is held fixed. Figure 6 decomposes foreign legs, total leg-kilometers, and total sea-days using equation (3). New-route contributions offset substantial losses on exited routes. The observed net change is exactly the sum of those components, so a small net outcome is compatible with extensive turnover. This is a descriptive result for Russia-origin dry-bulk operations, not a causal grain-only estimate.

[Figure 6 is about here]

Route survival and vessel histories show that the adjustment frequently reuses capacity from elsewhere in the network. Figure A7 contrasts unweighted survival with survival weighted by 2021 activity. Figure A8 separates vessels previously serving Russia from vessels newly observed on Russia-serving operations and documents the latter's prior connections to selected exporter networks. These histories suggest rematching of existing maritime resources, not necessarily newly built capacity. They parallel the supplier result without proving that the same origin–destination trade links and vessels can be joined transaction by transaction.

Transport time is an operational resource measure whose economic interpretation requires care. Hummels and Schaur (2013) establish that time can matter for trade, but longer sea-days in our records can reflect distance, speed, waiting, or differences in port-call sequences. Distance-adjusted timing does not provide sufficiently stable evidence to label the principal adjustment congestion. We therefore describe changed route and resource use rather than an independently identified decline in port efficiency.

Available monetary-cost observations do not identify a global access gradient. U.S. Census vessel import charges provide a positive annual comparison for one destination, but quarterly pre-period behavior is unfavorable; Figures A9 and A10 report the pair together. Public indicative freight quotes and tender observations add route-specific information but are sparse and not a globally comparable panel of realized contracts. We use this evidence to delimit what the model can quantify, not to certify that its implied wedge is observed freight or insurance.

7. A Conditional Model of Supply and Destination Access

The model isolates the allocation problem that aggregate recovery leaves unresolved. It takes origin–product supply shifts and the prewar feasible supplier network as inputs, then determines source prices and destination sourcing under persistent relationship weights and heterogeneous Russian access. It is a partial-equilibrium, conditional sourcing model rather than a household welfare model or a dynamic optimization model of supplier entry. Its purpose is to ask whether one parsimonious allocation mechanism can jointly accommodate expanding Russian shipments and the observed sourcing gradients.

7.1 Environment and normalization

The feasible set contains destination–origin–product links observed before the disruption. Let d, o, k, and t index destinations, origins, HS6 products, and years, with Russia denoted R. The support is

$$\mathcal{L}^0 = \{(d, o, k): x_{dokt} > 0 \text{ in at least one year of 2019–2021}\}. \quad (4)$$

Baseline expenditures are averages over 2019–2021 on this support. Write x^0_{dok} for a link's expenditure, $E^0_{dk} = \sum_o x^0_{dok}$ for market expenditure, $R^0_{ok} = \sum_d x^0_{dok}$ for origin–product revenue, and $s^0_{dok} = x^0_{dok}/E^0_{dk}$ for its share. Origin units and baseline wedges are normalized so baseline model prices are one; baseline price differences are absorbed into the expenditure calibration. Physical tonnes are recovered separately using observed baseline quantity coefficients. The annual equilibrium starts with $s_{dok,2021} = s^0_{dok}$, so it does not attempt to reproduce pre-2022 dynamics.

7.2 Procurement and relationship persistence

Procurement across feasible origins follows a constant-elasticity aggregator. For given nonnegative relationship weights A_{dokt}, the composite is

$$Q_{dkt} = \left[\sum_o A^{1/\sigma}_{dokt}\, q^{(\sigma-1)/\sigma}_{dokt}\right]^{\sigma/(\sigma-1)}, \sigma > 1. \quad (5)$$

Cost minimization delivers a demand schedule for each origin variety. Minimizing expenditure subject to equation (5), the first-order condition equates the purchaser price to the multiplier times the marginal contribution to the composite. Denoting the unit-expenditure function by P_{dkt}, homogeneity implies that the minimized expenditure is $P_{dkt}Q_{dkt}$, and hence

$$q_{dokt} = A_{dokt}(P_{dkt}/p_{dokt})^{\sigma} Q_{dkt}. \quad (6)$$

Substituting these demands into the aggregator gives the price index, and dividing link expenditure by total expenditure gives the source share:

$$P_{dkt} = \left[\sum_o A_{dokt}\, p^{1-\sigma}_{dokt}\right]^{1/(1-\sigma)}. \quad (7)$$

$$s_{dokt} = \frac{A_{dokt} p^{1-\sigma}_{dokt}}{\sum_j A_{djkt} p^{1-\sigma}_{djkt}}. \quad (8)$$

Relationship weights evolve with the previous allocation rather than through an estimated entry technology. Specifically,

$$A_{dokt} = (s^0_{dok})^{1-\rho}(s_{dok,t-1})^{\rho}, 0 \le \rho < 1. \quad (9)$$

These weights are not renormalized to sum to one each year. Their scale therefore affects the composite price index as well as relative sourcing. This is a substantive feature of the maintained aggregator, not solely a numerical implementation detail. Persistence is a reduced-form law of motion; the model contains no forward-looking search decision, sunk entry cost, or choice to create a wholly unsupported link.

Composite import demand responds to its normalized price index with a calibrated elasticity. Let hats denote ratios to the normalized baseline. We impose

$$\hat{Q}_{dkt} = \hat{P}^{-\eta}_{dkt}, \hat{E}_{dkt} = \hat{P}^{1-\eta}_{dkt}. \quad (10)$$

The main exercise uses $\eta = 0.50$, with $\eta = 0.25$ as sensitivity. These are scenario assumptions, not elasticities identified by the annual total-import regression. Because the model excludes domestic consumption alternatives and household income, the composite cannot be interpreted as a complete consumption basket.

7.3 Transaction wedges, supply, and equilibrium

The purchaser–producer wedge is a payment wedge rather than physical iceberg loss. Purchaser prices satisfy $p_{dokt} = w_{okt}\tau_{dokt}$, and exporters receive link expenditure divided by τ_{dokt}. A transaction generating purchaser spending of one therefore delivers $1/\tau_{dokt}$ to the producer. The remainder is not assigned between real intermediation costs and rents in the model. This convention matches the implemented market-clearing equation and precludes treating all wedge payments as destroyed resources.

Supply is specified in normalized origin–product units. With an imposed shift $\omega_{okt} > 0$ and supply elasticity ϵ,

$$\hat{Q}^{S}_{okt} = \omega_{okt}\hat{w}^{\epsilon}_{okt}. \tag{11}$$

Producer receipts equal price times supply, so clearing requires

$$R^{0}_{ok}\omega_{okt}\hat{w}^{1+\epsilon}_{okt} = \sum_{d} E^{0}_{dk}\,\hat{E}_{dkt}s_{dokt}/\hat{\tau}_{dokt}. \tag{12}$$

The main specification sets $\epsilon = 0$ and solves for prices that clear the imposed supply quantities. Russian shifts preserve the mirror-data relative HS6 pattern but receive a common annual multiplier so their baseline-tonnage-weighted mean equals the PORTSTAT index: 1.035, 1.634, and 1.819. Ukrainian and other-origin shifts are held at their observed-input paths. Applying a 2021-based throughput index to a 2019–2021 expenditure calibration is an explicit index-splicing assumption, not an assertion that the two baselines have identical levels. Observed throughput disciplines a scenario supply path; it does not identify technological capacity.

The Russian wedge is deliberately parsimonious and bounded exactly as in the solver. Non-Russian incremental wedges are normalized to one, and the post-2021 Russian component is

$$\log\hat{\tau}_{dRkt} = min\{\beta_A E^{R}_{d}, 0.50\}Post_t. \tag{13}$$

The upper bound prevents arbitrarily large implied wedges at high exposure; it is a maintained numerical and economic restriction, not an estimated threshold. The access component is persistent after 2021 rather than independently estimated for every product and year. A common Russian price component is absorbed into endogenous origin prices and imposed supply. Thus the model characterizes an implied exposure-related procurement friction, not the effects of an observed sanctions schedule.

The annual solution is sequential but not a claim of a unique global dynamic equilibrium. Given lagged shares, the solver updates source prices until origin–product excess demand is sufficiently small, calculates new shares, and carries those shares into the next year. Numerical convergence is checked for each retained

parameter configuration. No general uniqueness theorem or forward-looking welfare optimality is asserted for this calibrated system.

7.4 Calibration and untargeted implications

Calibration uses two Russian-share moments on the model-supported product sample. Model predictions and the corresponding observed shares are projected through equation (1). For fixed η, the selected grid point minimizes

$$\hat{\theta} = \arg\min_{\theta \in \Theta} \sum_{t=2022}^{2023} \left[\frac{\gamma_t^{R,m}(\theta) - \gamma_t^{R,d}}{max\{SE_t, c\}} \right]^2. \quad (14)$$

The parameter vector is $\theta = (\sigma, \rho, \beta_A)$, and the standard-error floor is $c = 0.0025$ when shares are fractions, equivalent to 0.25 percentage points. The grid considers substitution elasticities 3, 4.5, and 6; persistence values 0.50, 0.90, and 0.97; and access slopes 0, 0.25, 0.50, 0.75, 1, 1.5, 2, 3, and 4. The main selected configuration is 6, 0.50, and 1.50. Two moments cannot identify three unrestricted primitives: this is a restricted, exploratory calibration, not an exactly identified structural estimate or a preregistered model test.

[Table 4 is about here]

The fitted Russian-share path approximates the persistent reallocation but misses part of the first-year decline. On the model-supported data, coefficients are −3.11, −2.19, and −2.98 points in 2022–2024, compared with predictions of −1.81, −2.36, and −2.85. The 2024 coefficient is excluded from the calibration objective, but the year has been examined in the research process. We therefore call it an untargeted diagnostic, not a pristine out-of-sample forecast.

The core-incumbent moments provide a substantive additional check and reveal underprediction. After excluding Russia and Ukraine from the incumbent definition, observed coefficients on the same supported products are 2.13, 1.94, and 3.10 points, against model predictions of 1.20, 1.51, and 1.70. These moments are not calibration targets. Figure 7 shows both panels in the same units, making the success in direction and the shortfall in magnitude equally visible.

[Figure 7 is about here]

The model's relationship use does not have a validated one-to-one mapping into vessel counts. An earlier mapping to Kpler voyage frequency produced the wrong sign, so shipping is not included among the model-fit moments. The maritime evidence supports the separate observation of operational rematching. This distinction keeps the quantitative exercise focused on what its procurement structure can actually predict.

8. Common Access: A Conditional Counterfactual

The counterfactual asks how sourcing would differ if the exposure-related component of Russian access were equalized while the recovered supply path remained available. It changes one component of the calibrated environment and resolves source prices and allocations. The comparison is informative about the role of that component inside the model, not about the effect of lifting every sanction or restoring the economy to a no-war path.

Common access is implemented by setting the Russian access slope to zero:

$$\beta_A^{CF} = 0. \tag{15}$$

All other inputs remain unchanged: Russian throughput scaling and product mix, Ukrainian and other-origin supply shifts, baseline feasible links, persistence, and demand assumptions. The counterfactual therefore retains unequal inherited supplier weights and endogenous prices. It does not impose equal realized Russian shares across destinations or freeze 2021 procurement shares.

Removing the exposure-related component largely removes the negative Russian sourcing gradient. The fitted coefficients of −1.81, −2.36, and −2.85 become 0.02, 0.75, and 0.87 points in 2022–2024. The corresponding core-incumbent coefficients fall from 1.20, 1.51, and 1.70 to 0.06, −0.35, and −0.46. Figure 8 displays the two allocation paths. The residual gradients reflect inherited relationships and other equilibrium adjustments, not an incomplete numerical removal of the access parameter.

[Figure 8 is about here]

The aggregate comparisons are small in physical quantity but larger in nominal spending and transport resources. Across the two demand-elasticity scenarios, the fitted-access model differs from common access by less than 0.1 percent in aggregate import quantity, approximately 0.4–1.9 percent in nominal value, and approximately 0.5–1.8 percent in trade-weighted ton-kilometers over 2022–2024. Figure A11 reports annual values and sensitivity ranges. These are comparisons between two model allocations, not estimates of how observed world trade would have changed absent the invasion.

The transport calculation converts normalized link changes back into the units observed before the shock. Where baseline tonnes q_{dok}^0 are available, the implemented mapping is

$$q_{dokt}^{tons} = q_{dok}^0 \frac{\hat{E}_{dkt} s_{dokt}}{s_{dok}^0 \hat{w}_{okt} \hat{\tau}_{dokt}}. \tag{16}$$

Ton-kilometers multiply those link quantities by the maintained distance measure and aggregate on observed quantity support. This is not a modeled vessel itinerary or a change in routing geography within a link. Likewise, a higher nominal import bill can arise mechanically from the demand assumption when $\eta < 1$. Neither measure identifies a loss in household purchasing power.

Welfare remains outside the identified content of the exercise. The model does not specify who receives intermediation payments, which portion uses real resources, how border prices pass through to retail prices,

or how households substitute toward domestic goods and draw down inventories. The conditional counterfactual quantifies an allocation difference while holding those unresolved margins outside the system. Its useful conclusion is that supply recovery need not eliminate an access-related sourcing gradient, not that equalizing access yields a known welfare gain.

9. Conclusion

Russian grain shipments recovered through a changed trading network rather than a simple return to the earlier allocation. Greater prewar dependence predicts a persistent decline in Russian sourcing shares, offset substantially by durable alternative suppliers. The result appears both in the global panel and within an independently defined emerging and developing economy sample. Maritime records document route replacement and resource rematching beneath the recovered seaport total.

The distinction between aggregate resilience and continuity of relationships is the central economic result. A country can face a changed procurement environment even as its former supplier ships more to the world. Established alternatives can facilitate substitution without proving that adjustment was costless. Measuring these margins requires information on destinations, supplier histories, and physical operations rather than an exporter total alone.

The conditional model clarifies this distinction without converting it into an identified sanctions or welfare claim. An exposure-related procurement wedge can accommodate recovered supply and bilateral reallocation; equalizing that component changes the model's allocation substantially more than its total physical shipments. Identifying the incidence of those changes requires additional evidence on realized bilateral charges, price transmission, and the recipients of intermediation payments. The present evidence establishes the reorganization of access, not its final distributional cost.

Appendix. Additional Measurement and Diagnostic Details

The supplementary results preserve distinctions that matter for interpretation but do not organize the main narrative. Figure A1 presents annual total imports and Figure A2 monthly sourcing; Table A2 reports total-import reporting-support diagnostics. Figures A3–A4 examine alternative matched-route and vessel-size margins; Figure A5 reports political supplier-matching diagnostics. Figures A6–A8 retain the PORTSTAT–Kpler measurement bridge and S&P route and vessel histories. Figures A9–A10 pair annual U.S. monetary-charge evidence with its quarterly stress test. Figure A11 reports conditional aggregate counterfactual ranges. Table A1 presents the emerging-economy linear-trend and income-classification checks.

The emerging-economy classification is reproducible independently of trade outcomes. Membership comes from IMF April 2021 World Economic Outlook Table E, pages 109–110, with explicit ISO3 mappings. The 152-country estimation set is its intersection with the global regression sample, not the residual after deleting advanced countries. The World Bank check uses the pre-existing 2021 low-, lower-middle-, and

upper-middle-income indicator and includes 133 destinations with 797 observations. The three source-share outcomes use the same support within each group.

Country-pair durability and product-level feasibility serve different purposes. The incumbent outcome asks whether a destination already bought cereals repeatedly from an origin. The model asks which destination–origin–HS6 links can be used on a fixed prewar support. A product link can be newly active relative to 2021 while belonging to a long-standing country-pair relationship, and a country-pair incumbent need not have supplied every product continuously. The distinction prevents supplier familiarity from being confused with an assumption of no product-level adjustment.

The model remains conditional on aggregate inputs that can themselves reflect the war. PORTSTAT provides realized throughput rather than an excluded supply instrument, and the Ukrainian and other-origin paths are held fixed in the counterfactual rather than forecast under a no-war scenario. Re-estimating equation (1) on the model-supported products creates the appropriate data comparator for Figure 7. Neither that comparator nor the counterfactual substitutes for the all-cereal reduced form in Table 3.

Access-related monetary evidence remains too sparse to decompose the model wedge. Public FAO route quotes are indicative observations rather than a dense panel of realized freight contracts, and observed tender windows combine changing freight and commodity prices. The U.S. charges series is a genuine monetary measure but covers only one destination and positive trade. Taken together, these observations are useful measurement checks, not instruments that identify an international destination-by-product access schedule.

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Table 1. Sample and Summary Statistics

Variable	N	Mean	SD	P25	P75
Panel A. Global					
Russian source share (%)	1223	6.17	16.00	0.00	2.51
Other-source share (%)	1223	90.40	18.88	90.79	100
Core-incumbent share (%)	1223	76.62	26.80	62.52	98.17
Prewar Russian dependence (%)	204	8.33	16.34	0.00	9.32
Prewar Ukrainian dependence (%)	204	1.97	5.37	0.00	0.50
Panel B. IMF EMDE					
Russian source share (%)	912	7.41	17.69	0.00	4.61
Other-source share (%)	912	89.50	20.42	89.40	100
Core-incumbent share (%)	912	73.46	27.74	56.93	97.32
Prewar Russian dependence (%)	152	10.09	18.03	0.00	12.68
Prewar Ukrainian dependence (%)	152	1.44	5.12	0.00	0.08

Notes: The regression period is 2019–2024. Share rows describe destination-year observations; prewar-dependence rows use one observation per destination, so exposure distributions are not weighted by years observed. IMF EMDE membership is fixed by April 2021 WEO Table E. All shares are percentages.

Table 2. Variable Definitions and Measurement Roles

Variable	Definition	Measurement
Russian/Ukrainian dependence	Mean annual cereal-import value share from the respective origin in 2017–2018.	BACI; entered in 10-pp units.
Russian source share	Russian-origin value divided by total cereal-import value.	BACI; percentage points.
Other-source share	Value from all origins except Russia and Ukraine divided by total.	BACI; percentage points.
Core-incumbent share	Current share from non-Russian/non-Ukrainian origins supplying the destination in every year of 2017–2019.	BACI; origin–destination history across cereals, not product-by-product continuity.
EMDE membership	Explicit April 2021 IMF WEO Table E membership intersected with the analysis sample.	152 destinations; includes emerging and developing economies.
Port throughput	Reported Russian seaport grain export throughput, indexed to 2021.	PORTSTAT; actual tonnage, not installed capacity.
Route activity	At least one observed voyage on a supported candidate route in a period.	Kpler; supported zero counts retained.
Log voyage frequency	Natural log of positive route-period voyage counts.	Kpler; conditional activity sample.
Route-resource accounting	Foreign legs, sum of leg distances, and sum of sequence-based sea time.	S&P; dry-bulk operations, not identified grain cargo.
Model feasible link	Positive destination–origin–HS6 trade at least once in 2019–2021, within the supported 22 products.	Baseline support; not first-ever supplier entry.
Access wedge	Purchaser-to-producer payment factor on Russian links; log factor bounded at 0.50.	Implied exposure-related component, not an observed sanctions rate.
Ton-kilometers	Model link tonnes times maintained bilateral distance, summed on quantity support.	Conditional resource accounting, not observed itineraries or welfare.

Notes: Cereals cover HS headings 1001–1008 in the reduced form. Missing quantities and absent reporting years are not converted into zero observations. Supplier durability and model product feasibility are distinct classifications.

Table 3. Prewar Dependence and Post-2021 Sourcing

	(1) Russian share	(2) Other sources	(3) Core incumbents
A. Global sample			
Russia exposure × Post	-2.345***	2.519***	2.068***
	(0.770)	(0.838)	(0.743)
Ukraine exposure × Post	0.788	1.471	3.339**
	(1.241)	(1.546)	(1.611)
Mean dependent variable	6.167	90.397	76.617
Observations	1,223	1,223	1,223
Destination FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes
B. IMF emerging market and developing economies			
Russia exposure × Post	-2.346***	2.450***	2.085***
	(0.816)	(0.884)	(0.784)
Ukraine exposure × Post	1.122	2.318	4.469**
	(1.670)	(1.992)	(1.958)
Mean dependent variable	7.415	89.496	73.463
Observations	912	912	912
Destination FE	Yes	Yes	Yes
Year FE	Yes	Yes	Yes

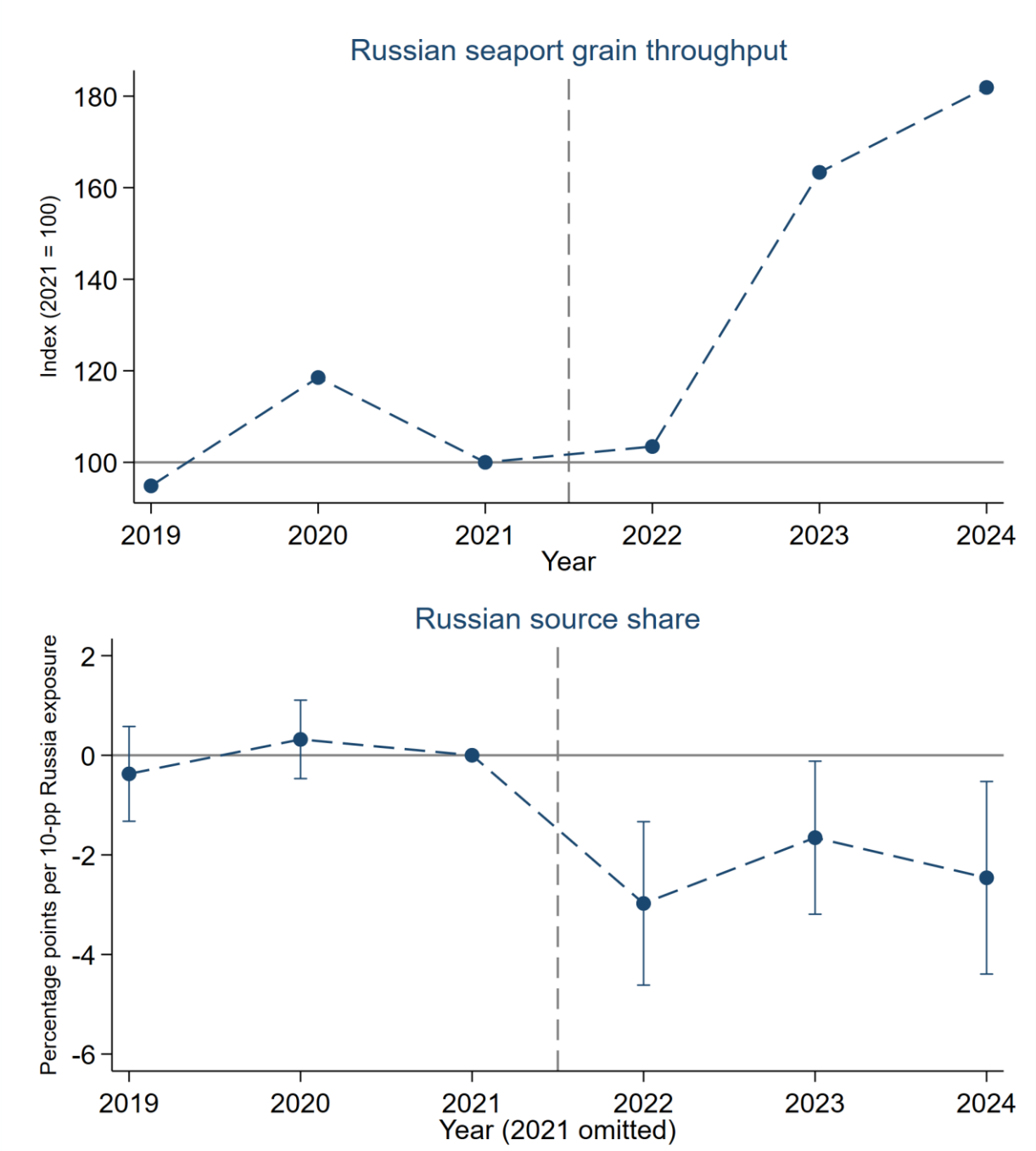
Notes: OLS estimates of equation (2), 2019–2024. Outcomes are percentage points and exposure is in 10-pp units. Destination-clustered standard errors in parentheses. Joint pre-period p-values test the 2019 and 2020 Russian interactions in equation (1), not equation (2). Core incumbents are a subset of other sources. *** p<0.01, ** p<0.05, * p<0.10.

Table 4. Quantitative Model: Inputs, Targets, and Interpretation

Component	Implementation	Interpretation
Scope	204 destinations; 22 supported HS6 products.	Observed model moments are recomputed on those products; all-cereal Figure 1 is different.
Baseline	Mean 2019–2021 expenditures and positive prewar feasible links.	2021 PORTSTAT growth index is spliced onto this normalization.
Russian supply path	Throughput ratios: 1.035, 1.634, 1.819. Mirror relative product mix retained.	Realized throughput is a conditional input, not identified capacity.
Main configuration	Substitution 6; persistence 0.50; access slope 1.50; demand elasticity 0.50; supply elasticity 0.	Exploratory restricted-grid calibration; not identification of three primitives from two moments.
Target moments	2022–2023 Russian-share gradients on model product support.	2024 and all core-incumbent moments excluded from objective, but previously examined.
Access formula	Russian log payment wedge is min(slope × dependence, 0.50).	The bound and payment-revenue convention are retained exactly.
Untargeted fit	Correct signs; underpredicts incumbent-supplier response.	Shipping measurement equation is not validated.
Common access	Set access slope to zero and re-solve source prices.	Retains all supply shifts, network support, and persistence; not a no-war economy.
Aggregate ranges	Demand elasticity 0.25 versus 0.50.	Scenario sensitivity, not statistical confidence intervals or welfare bounds.

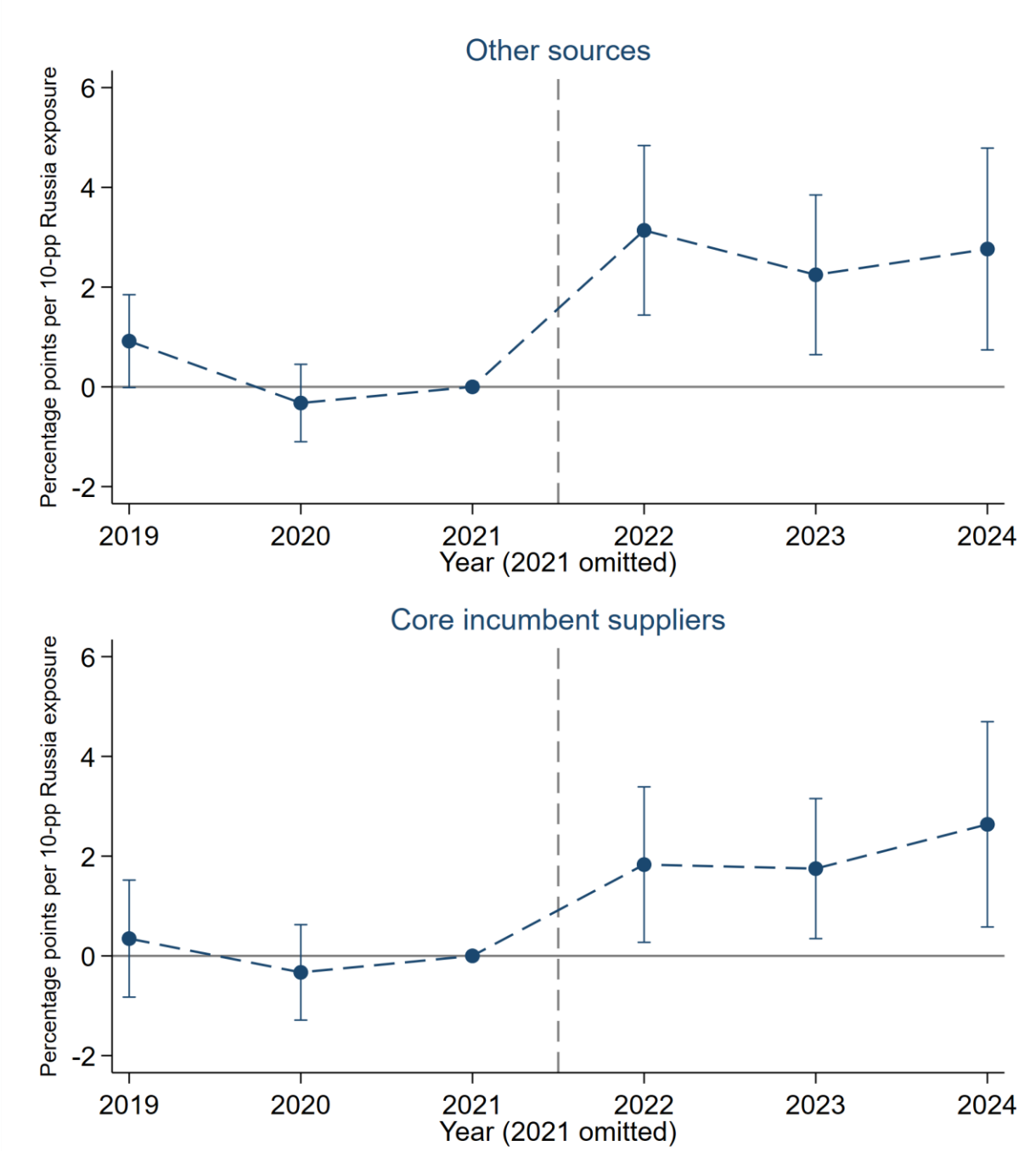
Notes: Equations (4)–(16) describe the numerical implementation. The corrected core-incumbent measure excludes Russia and Ukraine. Existing equilibrium and counterfactual outputs are retained; their economic interpretation is corrected to match the code.

Figure 1. Recovered Seaport Shipments and Destination Reallocation



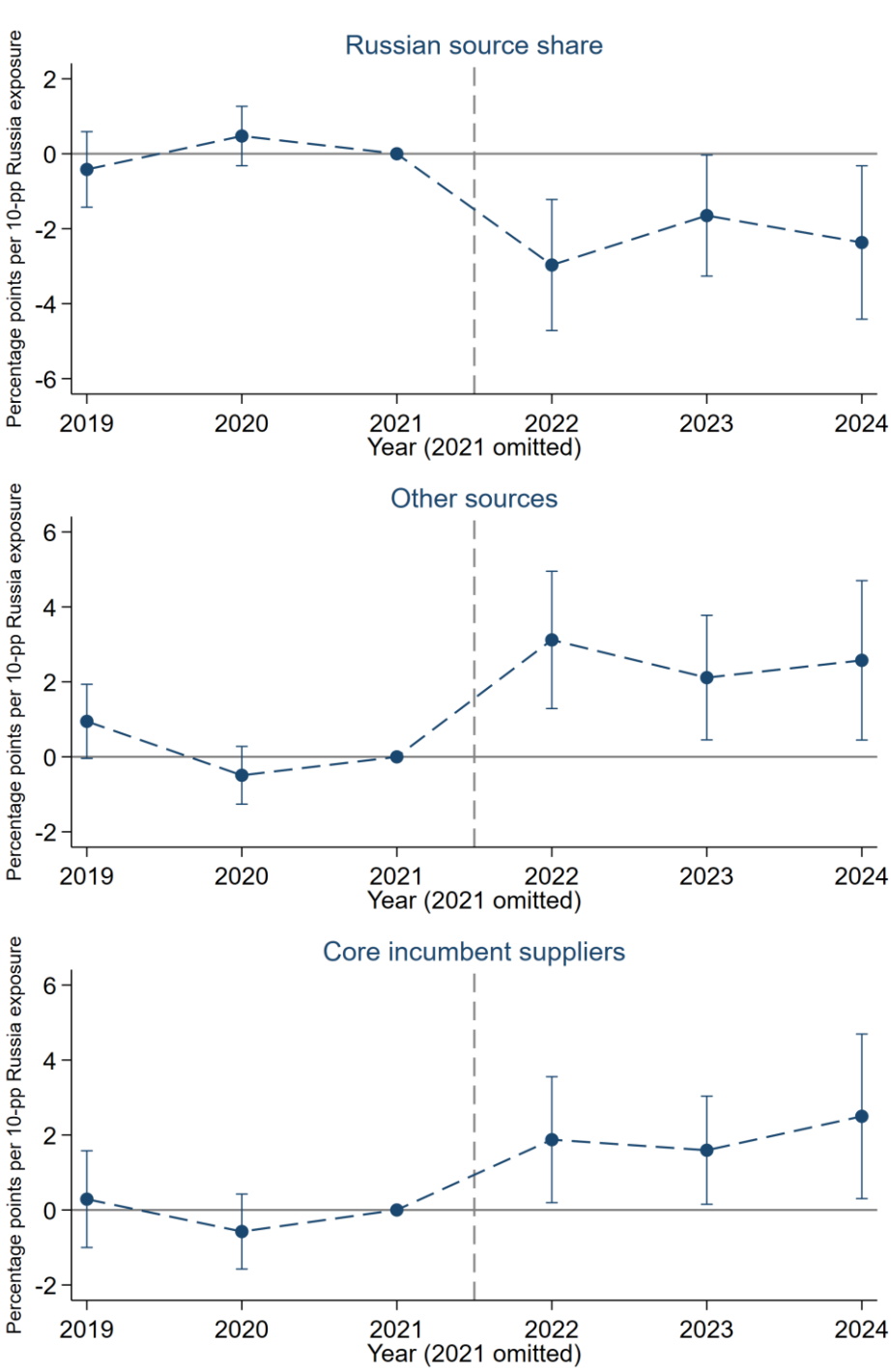
Notes: Upper panel: PORTSTAT national grain export-throughput index (2021 = 100). Lower panel: all-cereal global equation (1), controlling for Ukrainian exposure, destination and year FE; 2021 omitted. Pointwise destination-clustered 95% intervals. The vertical line separates 2021 and 2022. These panels measure different aggregation levels.

Figure 2. Supplier Substitution toward Other and Core-Incumbent Origins



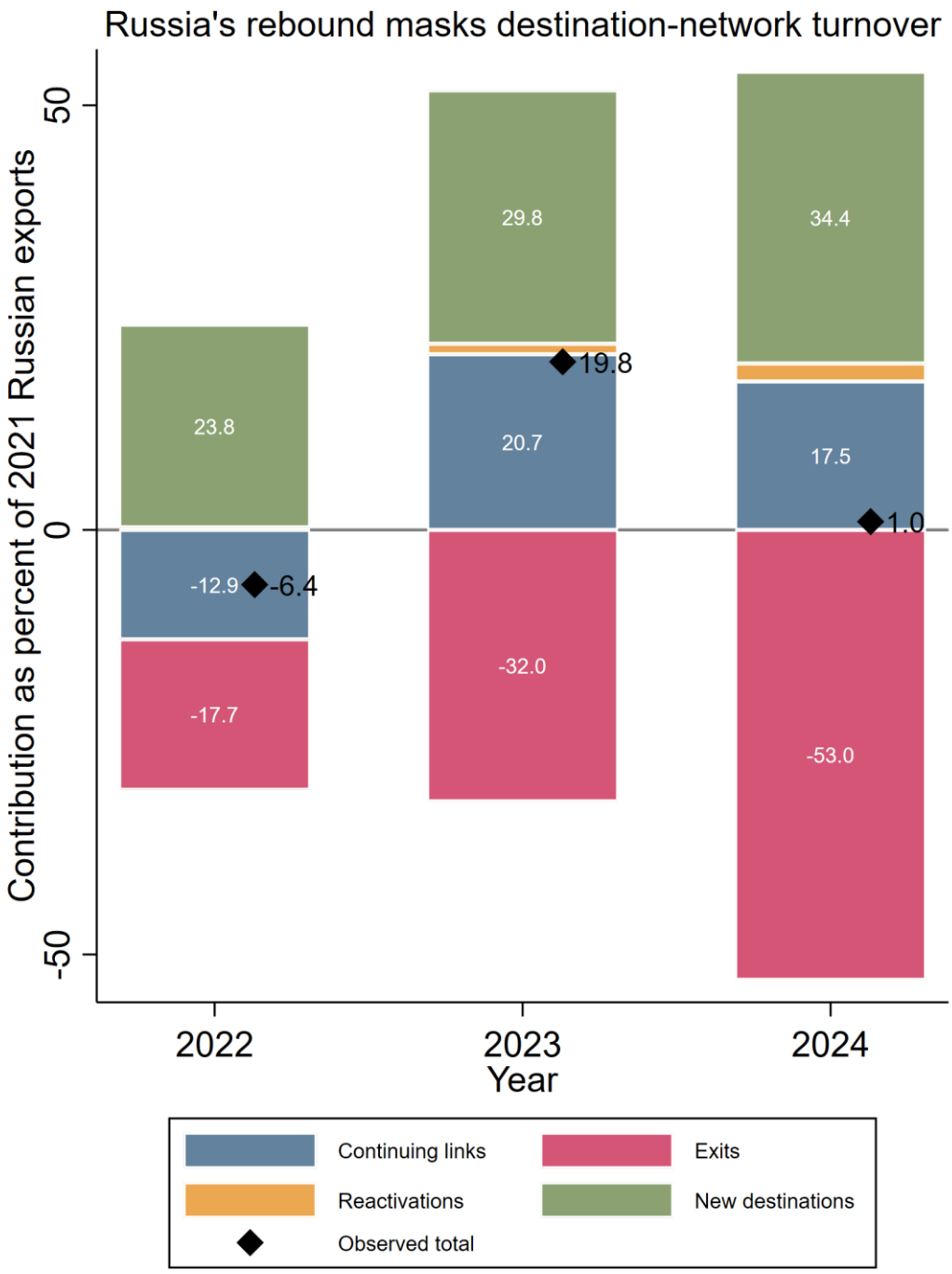
Notes: Global all-cereal equation (1); units are percentage points per 10-pp 2017–2018 Russian dependence. Core incumbents are non-Russian/non-Ukrainian origin–destination cereal relationships active in all of 2017–2019. Destination and year FE and Ukrainian exposure interactions included; destination-clustered 95% intervals. The broad other-source pre-period joint test rejects ($p = 0.038$); the core-incumbent test does not ($p = 0.434$).

Figure 3. Sourcing Reallocation in Emerging Market and Developing Economies



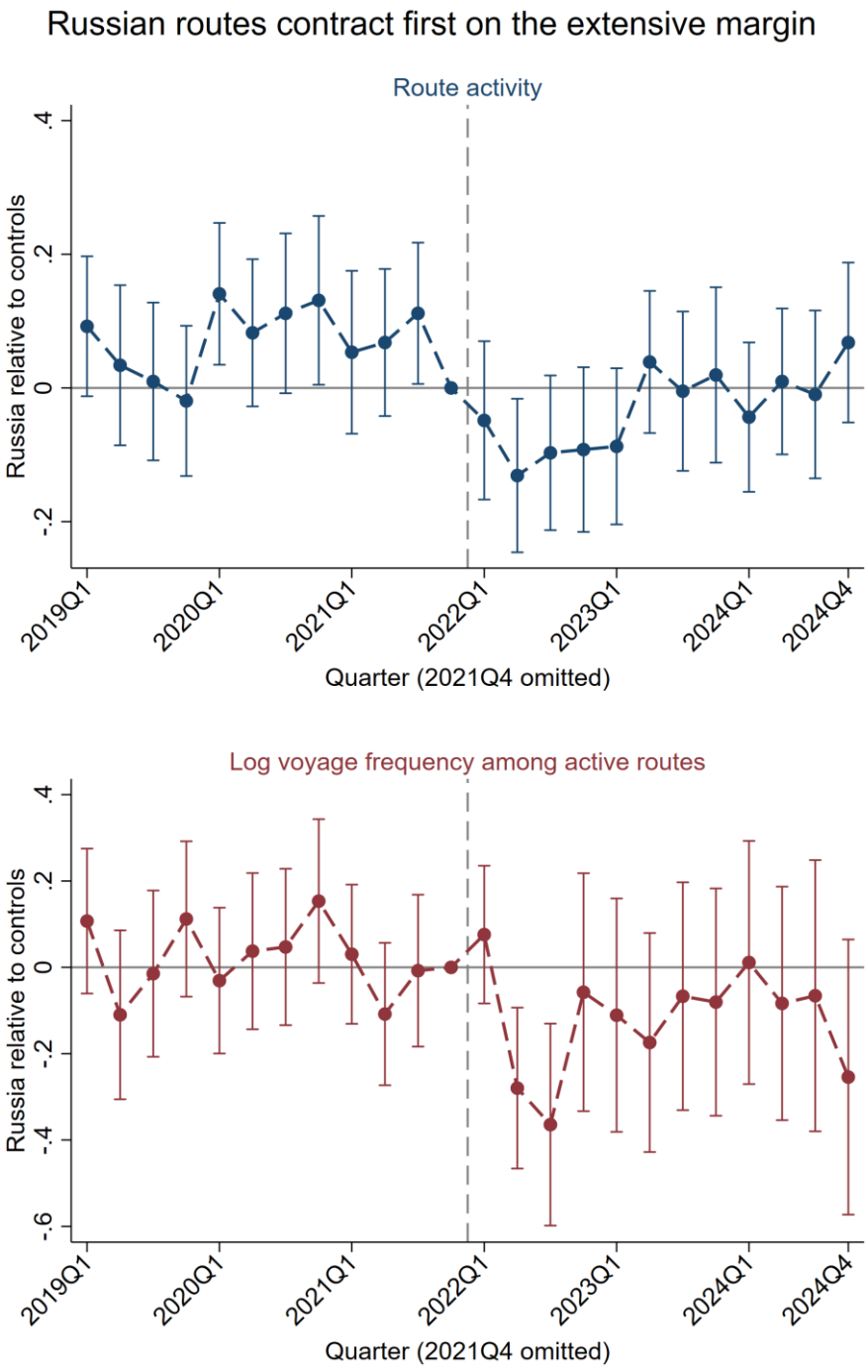
Notes: Equation (1) on IMF April 2021 EMDE membership intersected with the global sample: 152 destinations, 912 observations. Same all-cereal outcomes and exposure units as Figures 1–2. Destination and year FE; Ukrainian exposure interactions; destination-clustered 95% intervals. Joint 2019–2020 p-values are 0.184, 0.014, and 0.235, respectively. This is a within-group scope check, not a test of differences from advanced economies.

Figure 4. Trade-Link Accounting



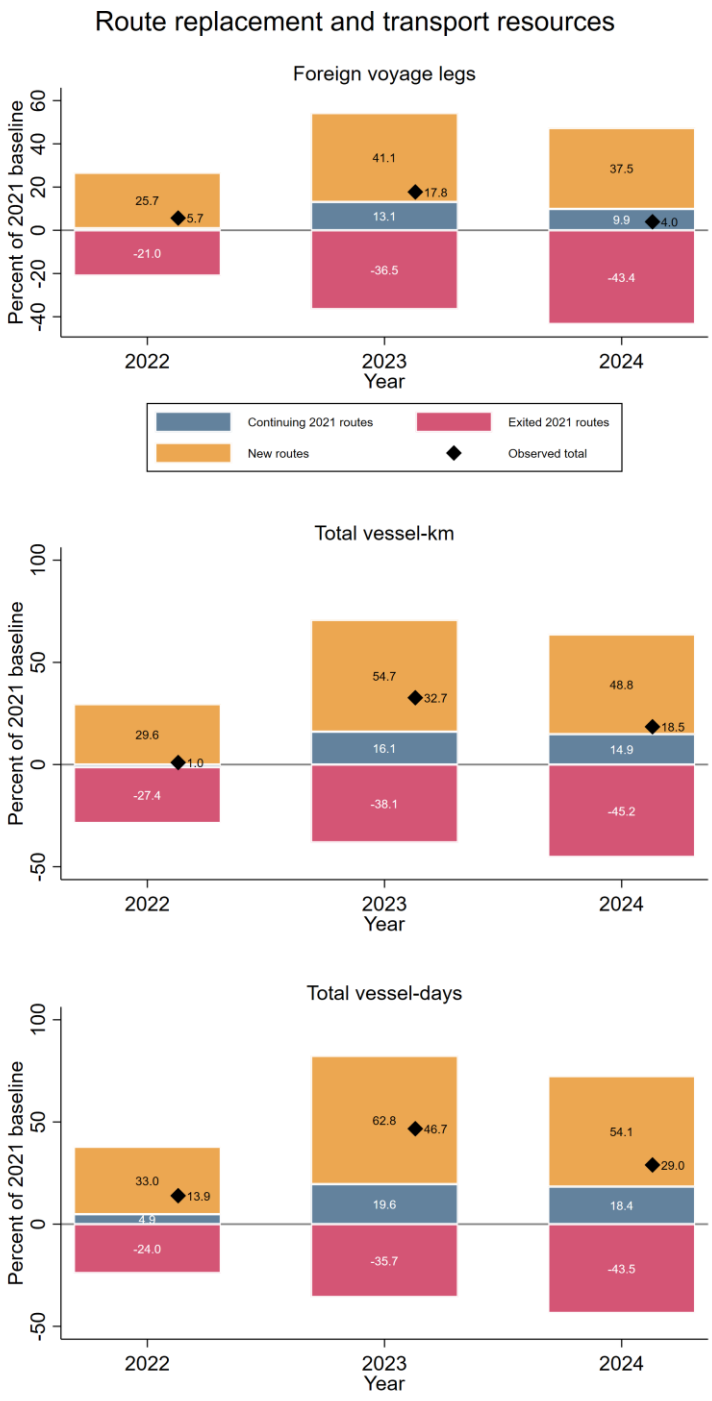
Notes: The figure decomposes observed post-2021 changes into continuing-link changes, exited-link losses, and new-link gains on a common accounting support. Components sum to the observed total change.

Figure 5. Kpler Route Activity and Voyage Frequency



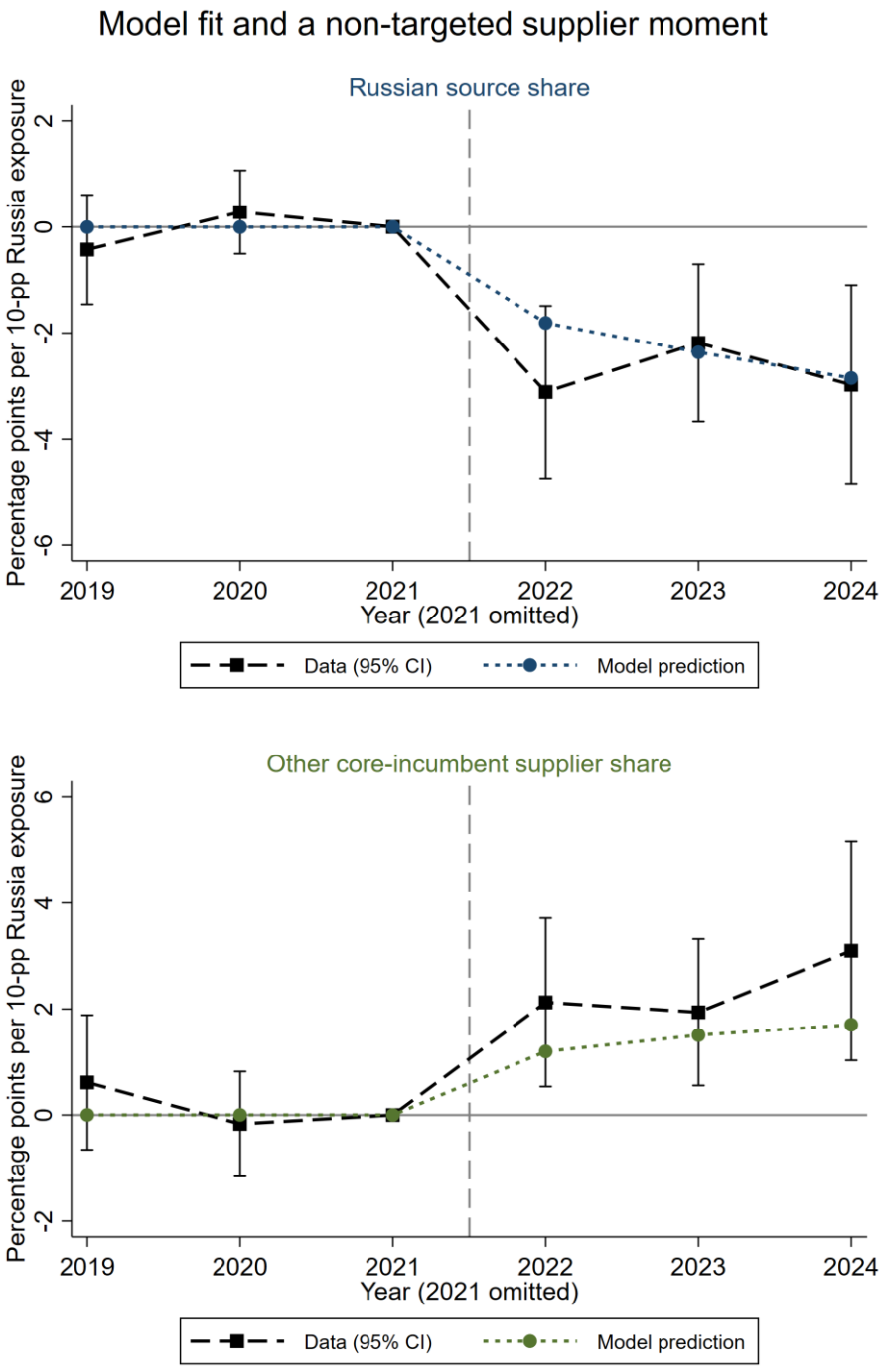
Notes: Upper panel: route activity retains supported zero-voyage periods. Lower panel: natural log of voyage counts conditional on positive activity. Route and destination-by-quarter FE; destination-clustered 95% intervals. Controls and matching weights use pre-2022 information. Candidate routes are not verified grain cargoes. Conditional-frequency selection and pre-period movements limit causal interpretation.

Figure 6. S&P Route and Transport-Resource Accounting



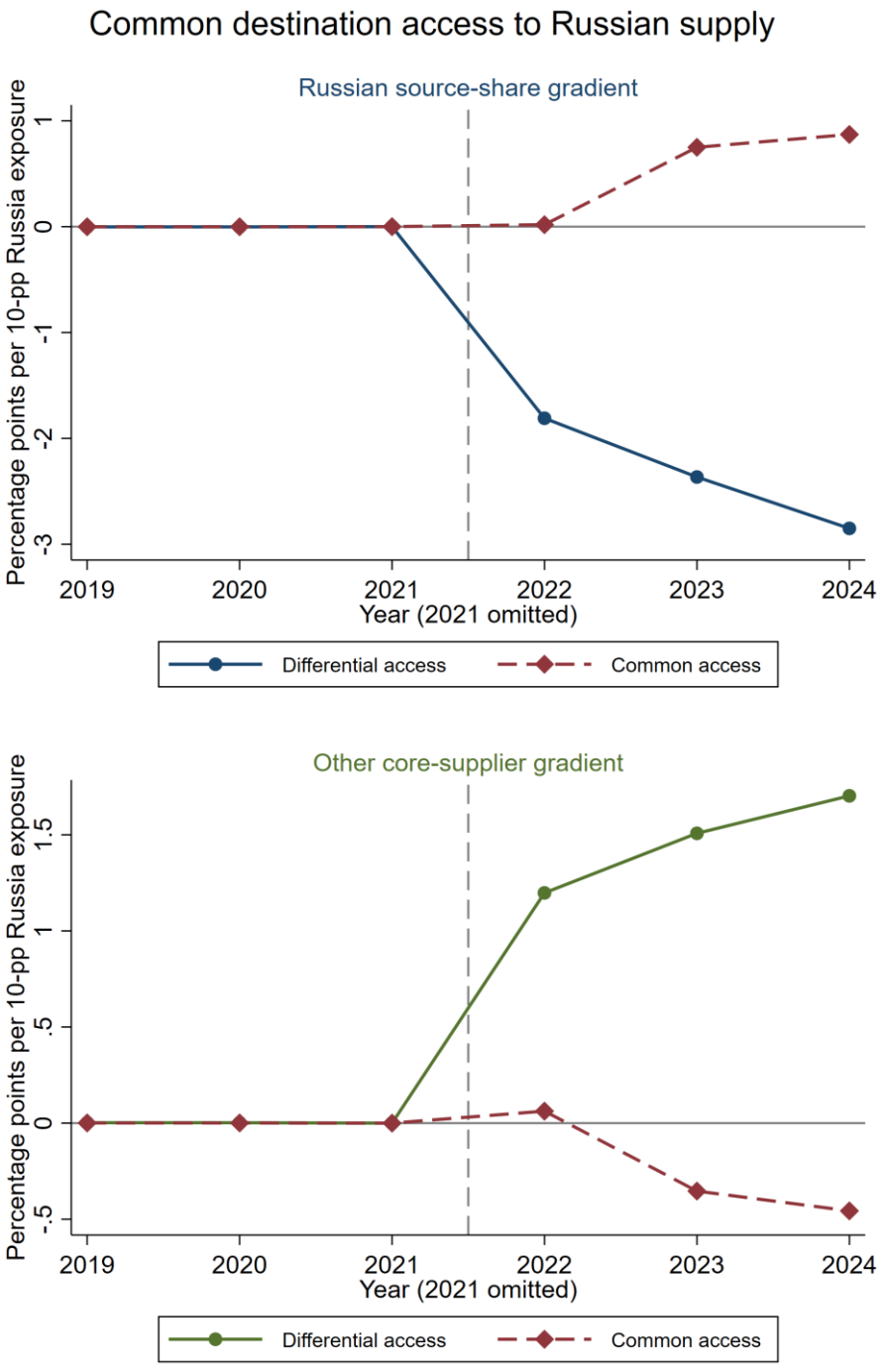
Notes: Exact accounting is relative to the fixed-2021 port-to-port route set. New-route gains plus continuing-route changes and exited-route losses equal the observed change in each transport-resource measure; 2025 is diagnostic only where displayed.

Figure 7. Model Fit and Untargeted Incumbent-Supplier Moments



Notes: Data and model predictions use the same 22 supported HS6 products, rather than the all-cereal outcomes in Figures 1–3. The 2022–2023 Russian-share gradients alone enter the grid objective. The 2024 Russian gradient and all corrected core-incumbent gradients are untargeted diagnostics. Data bars are 95% intervals; the model path is not a confidence interval. Shipping is not a structural fit moment.

Figure 8. Common-Access Counterfactual



Notes: Fitted model versus the common-access counterfactual (access slope set to zero). Both are model allocations, not observed treatment effects. Russian throughput scaling, product mix, Ukrainian and other-origin supply, prewar feasible links, persistence, and endogenous source-price adjustment are maintained. This is not a sanctions-removal or welfare experiment.

APPENDIX

Table A1. Scope and Differential-Trend Sensitivity

	(1) Russian share	(2) Other sources	(3) Core incumbents
A. IMF EMDE: exposure-specific linear trends			
Russia exposure × Post	-3.111***	3.570***	1.834**
	(0.886)	(0.952)	(0.917)
Ukraine exposure × Post	-0.174	2.406	6.351***
	(1.645)	(2.665)	(1.884)
Mean dependent variable	7.415	89.496	73.463
Observations	912	912	912
Destination and year FE	Yes	Yes	Yes
Russia/Ukraine exposure × linear time	Yes	Yes	Yes
B. World Bank 2021 low/middle-income sample			
Russia exposure × Post	-2.260***	2.115**	1.842**
	(0.831)	(0.886)	(0.791)
Ukraine exposure × Post	1.369	2.441	4.764**
	(1.702)	(2.084)	(2.078)
Mean dependent variable	8.255	88.795	71.260
Observations	797	797	797
Destination and year FE	Yes	Yes	Yes
Russia/Ukraine exposure × linear time	No	No	No

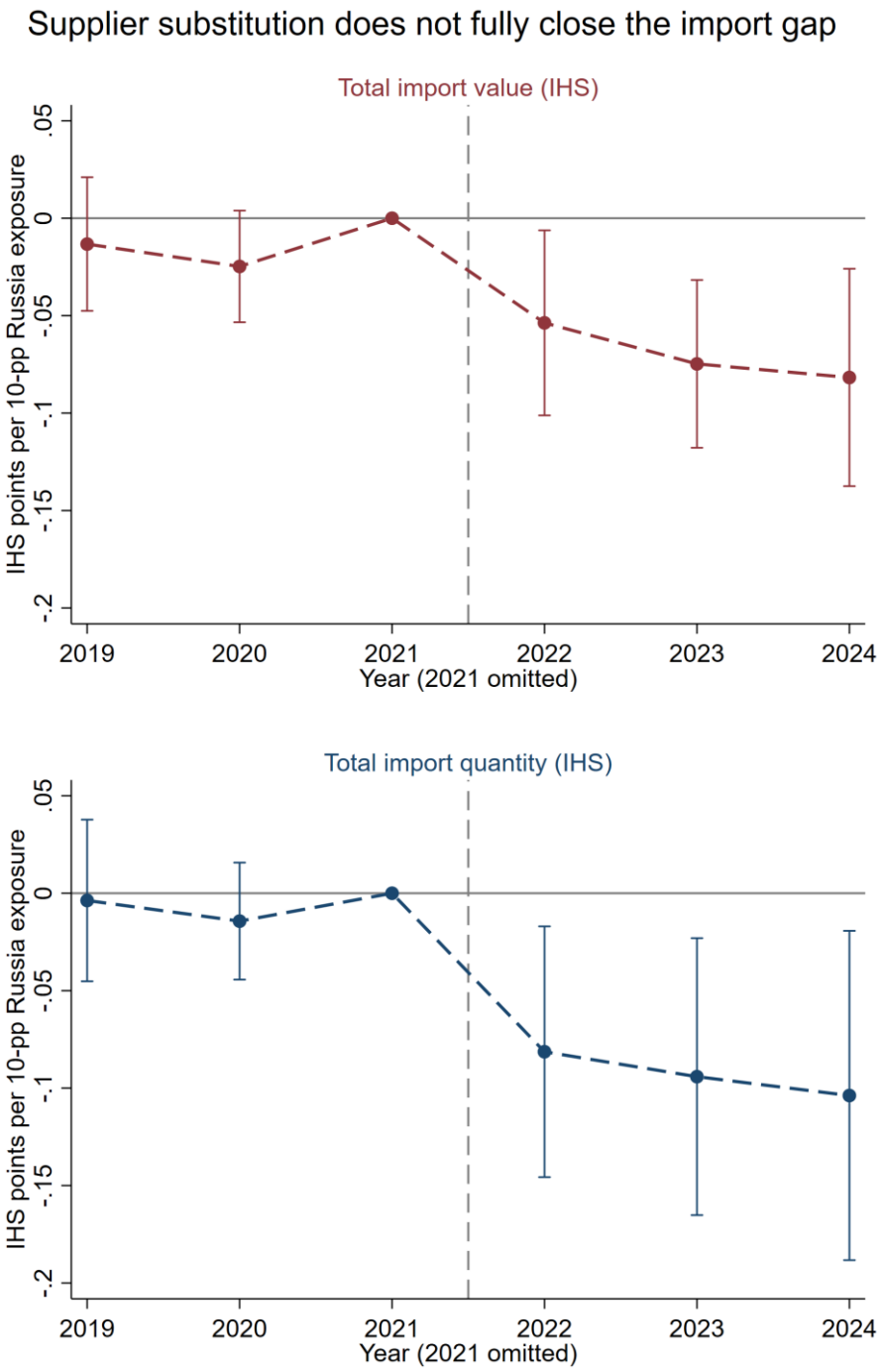
Notes: Same outcome and exposure units as Table 3. Panel A estimates the Russian and Ukrainian exposure-specific linear trends jointly over 2019–2024; it is not a trend estimated only from prewar data. Panel B changes classification to World Bank 2021 low-, lower-middle-, and upper-middle-income economies. Destination-clustered standard errors; *** p<0.01, ** p<0.05, * p<0.10.

Table A2. Total Imports: Annual and Monthly Reporting-Support Diagnostics

	IHS import value	IHS import quantity
A. BACI annual, 2020–2024		
Russia exposure × Post	-0.0552**	-0.0828**
	(0.0226)	(0.0351)
Mean dependent variable	12.458	13.354
Observations	1,019	999
Ukraine exposure × Post	Yes	Yes
Destination FE	Yes	Yes
Year FE	Yes	Yes
B. BACI annual, monthly-reporter countries, 2020–2023		
Russia exposure × Post	-0.0411	-0.0570
	(0.0275)	(0.0448)
Mean dependent variable	13.087	14.060
Observations	252	250
Ukraine exposure × Post	Yes	Yes
Destination FE	Yes	Yes
Year FE	Yes	Yes
C. Comtrade monthly, 2019–2023		
Russia exposure × Post	-0.0017	0.0074
	(0.0286)	(0.0334)
Mean dependent variable	10.390	11.184
Observations	3,634	3,225
Ukraine exposure × Post	Yes	Yes
Destination FE	Yes	Yes
Month FE	Yes	Yes
Destination × calendar-month FE	Yes	Yes

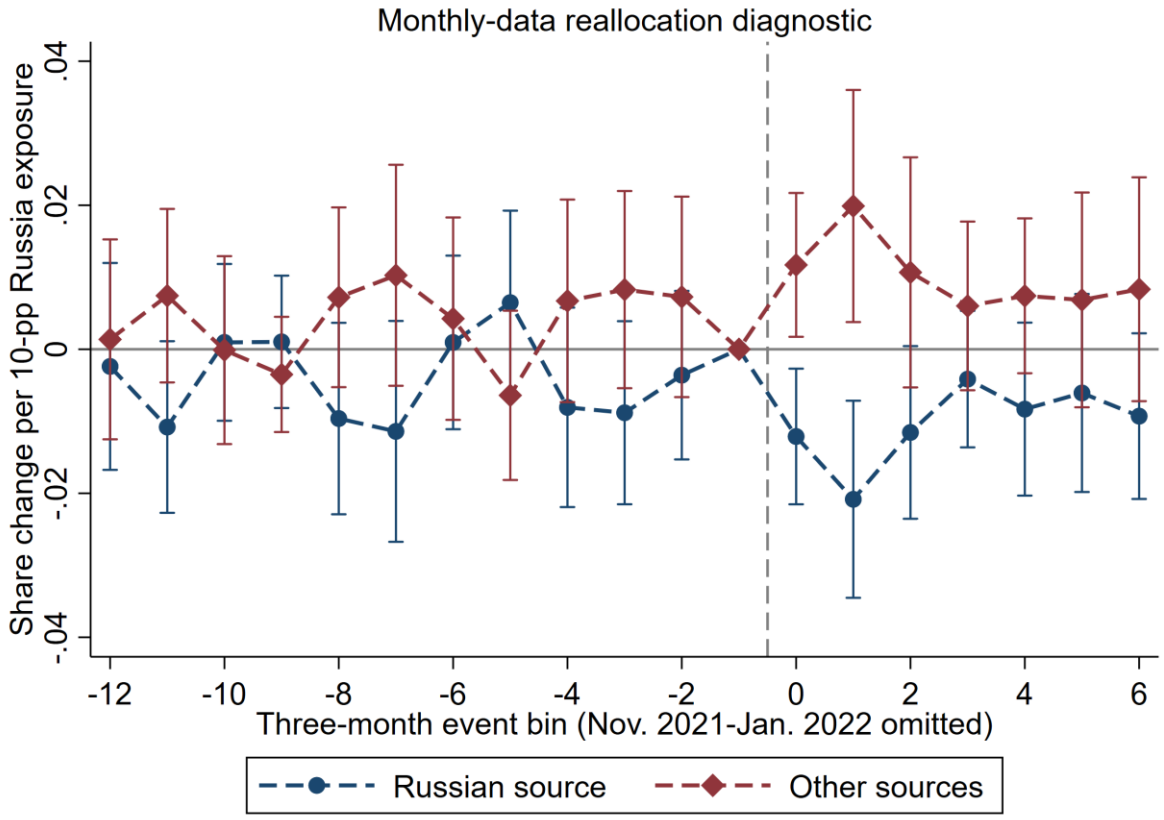
Notes: Archived frequency bridge, not the Table 3 sourcing specification. All columns use 2017–2019 dependence in 10-pp units, independently constructed from BACI in A–B and Comtrade in C. Annual post begins in 2022; monthly post begins February 2022. Samples and time windows differ as stated. Destination-clustered standard errors; overall R^2. Panels do not isolate frequency alone. *** p<0.01, ** p<0.05, * p<0.10.

Figure A1. Annual Total-Import Gap in the Main Annual Sample



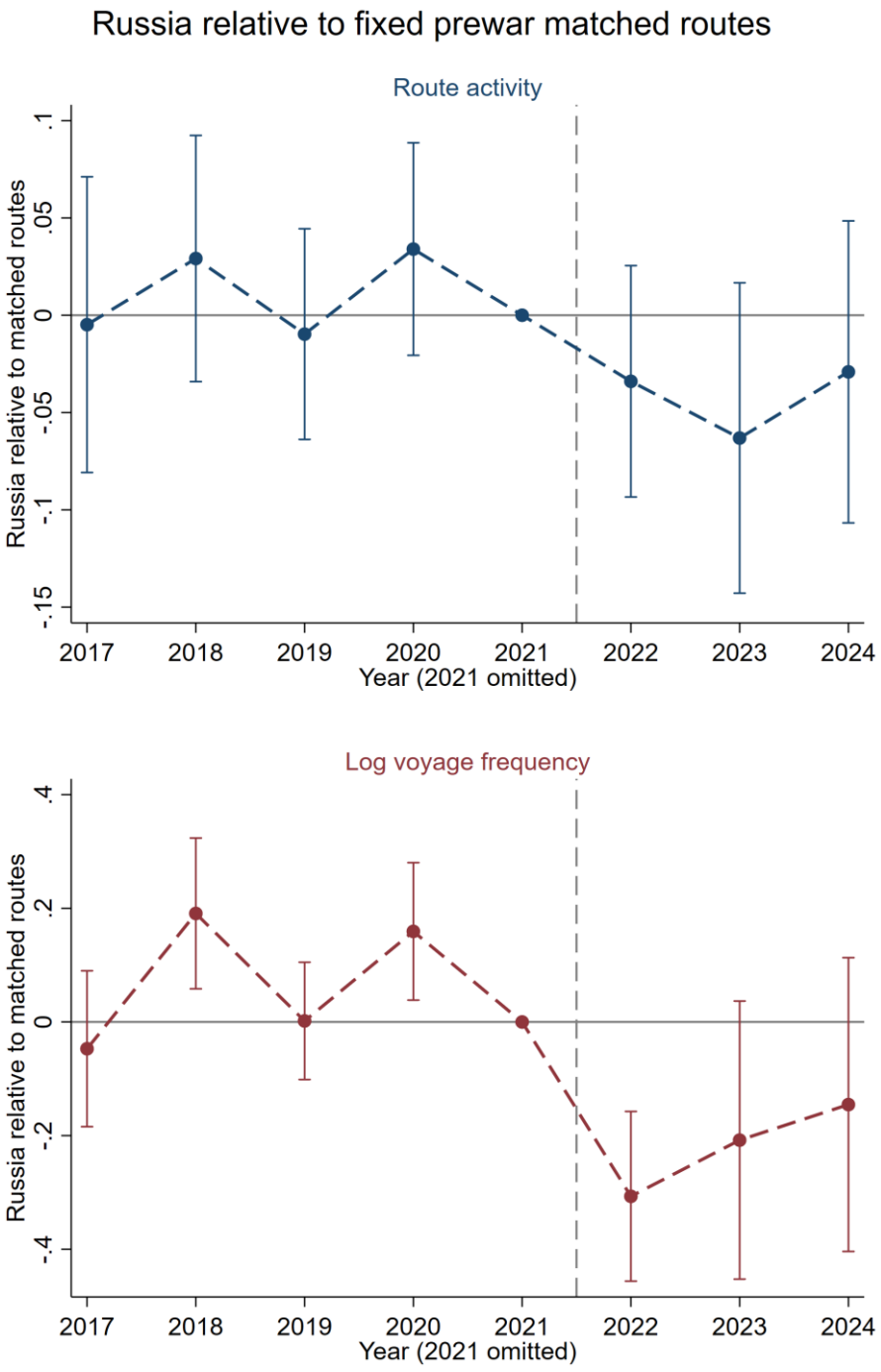
Notes: Annual customs-sample event studies for total import value and quantity. These estimates are reported as a sample-sensitive diagnostic, not as the paper's headline result.

Figure A2. Monthly Reallocation and Reporter-Sample Diagnostics



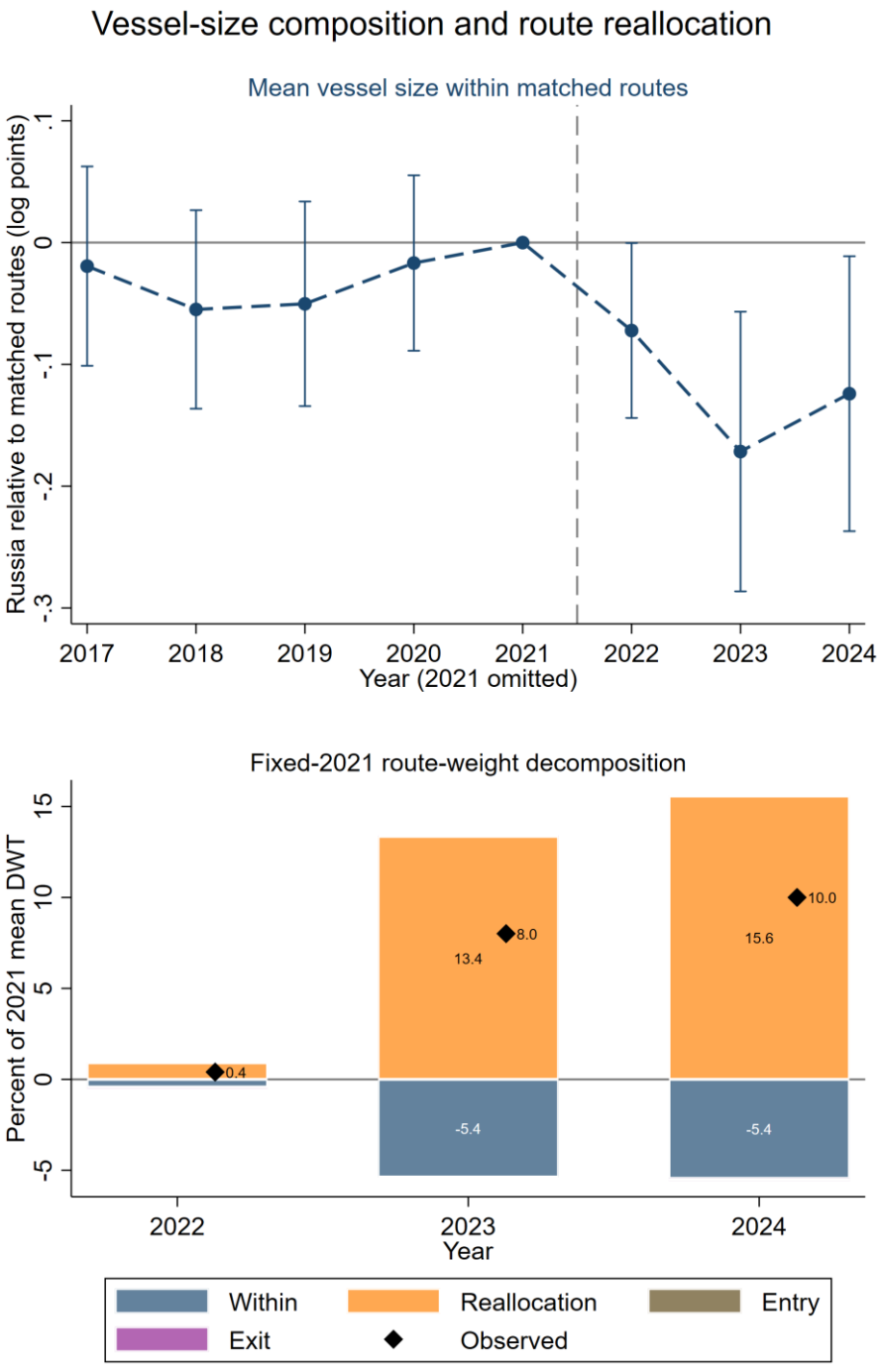
Notes: Monthly estimates use stable reporters and predetermined exposure definitions to distinguish frequency and sample composition from the annual results.

Figure A3. Kpler Matched-Route Estimates



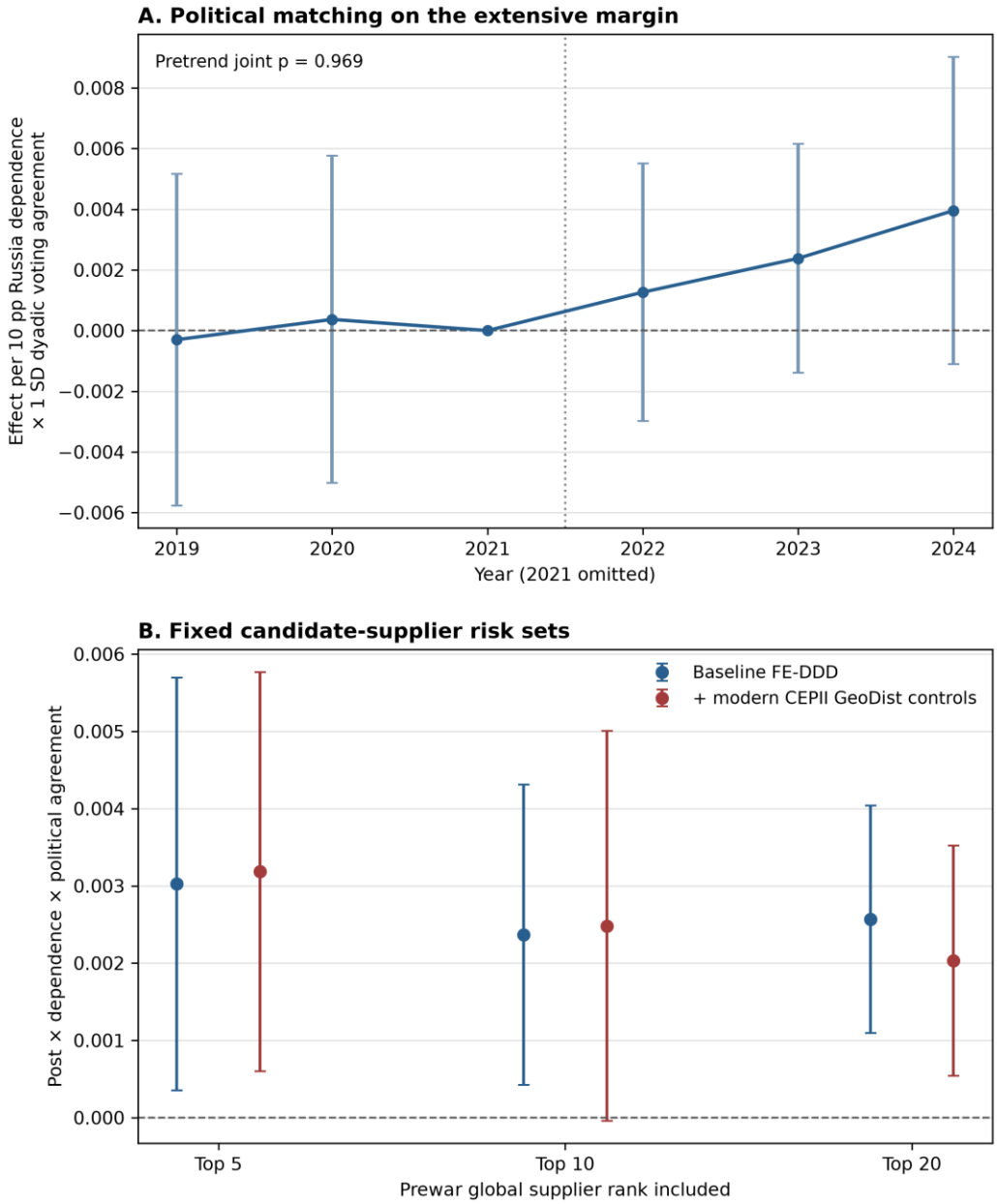
Notes: Russia-origin candidate routes are compared with predetermined matched export routes; 2021 is omitted and confidence intervals are clustered by destination. The frequency panel uses log(1 + voyage count), including supported zeros; Figure 5 instead uses log counts conditional on activity.

Figure A4. Vessel-Size Event Study and Fixed-Weight Decomposition



Notes: The event study conditions on matched routes; the accounting panel holds 2021 route weights fixed and separates within-route vessel-size change from route reallocation.

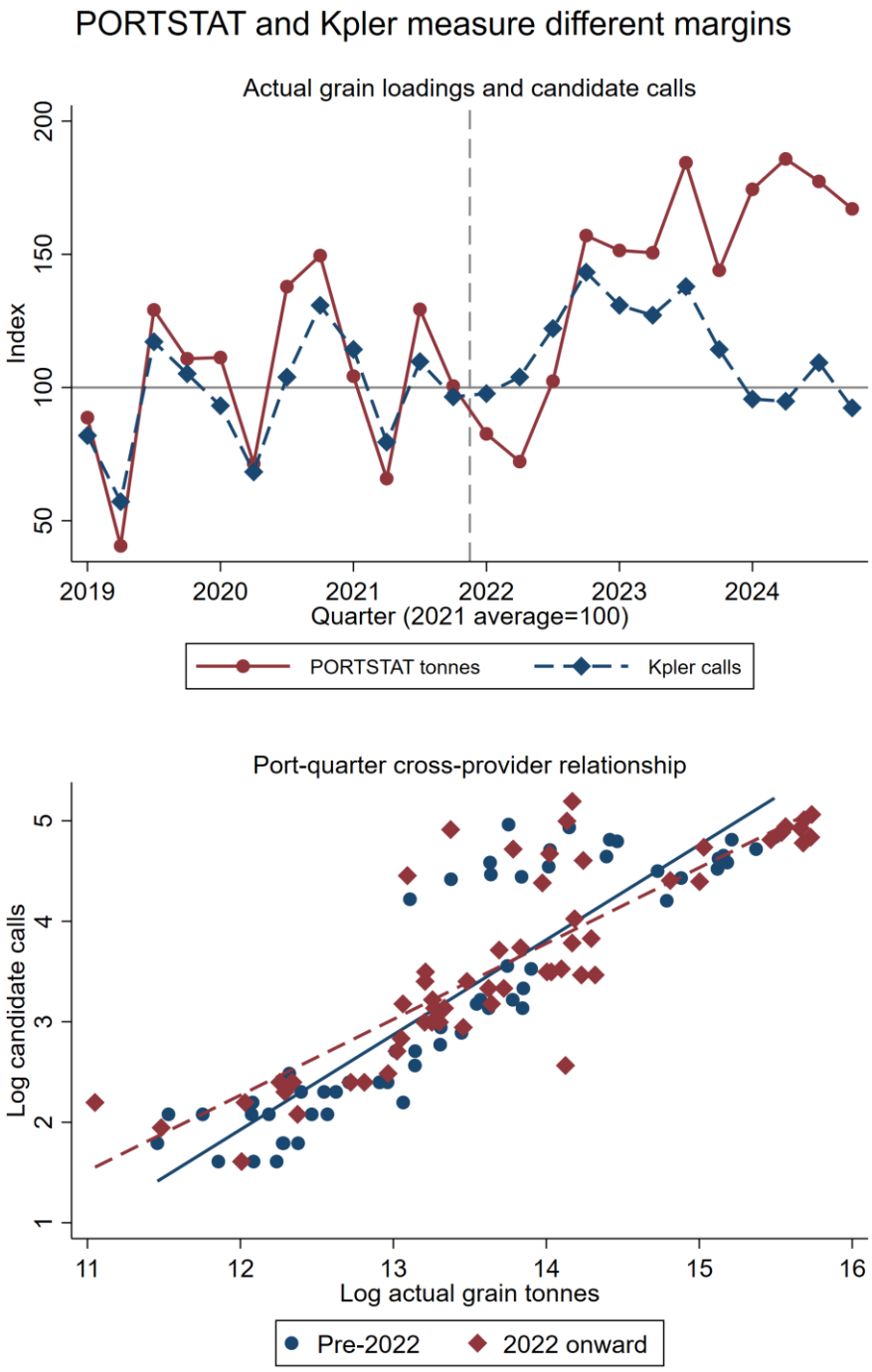
Figure A5. Political Similarity and Marginal Supplier Matching



Notes: fixed 2017–2018 candidate networks. Relationship, destination×HS6×year, and origin×HS6×year FE; destination-clustered 95% CIs. Modern CEPII controls include population-weighted harmonic distance, contiguity, common official language, colonial relationship, supplier rank, and pre-existing-link status.

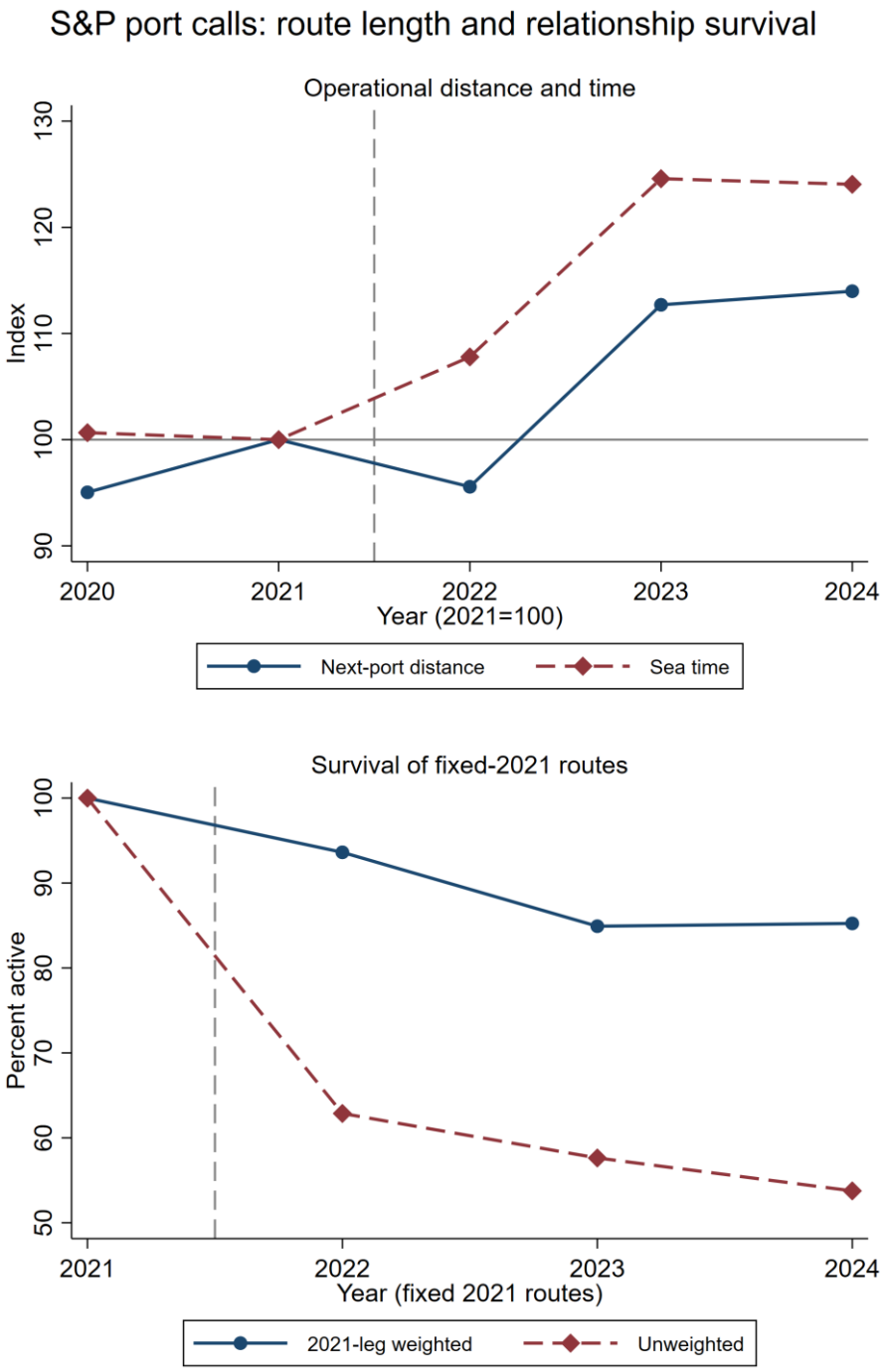
Notes: Candidate suppliers are fixed by prewar global rank. Specifications include relationship, destination-by-HS6-by-year, and origin-by-HS6-by-year fixed effects, with interacted CEPII geography, supplier-rank, and pre-existing-link controls. This is evidence on marginal link activation, not trade value or sourcing shares.

Figure A6. PORTSTAT–Kpler Measurement Bridge



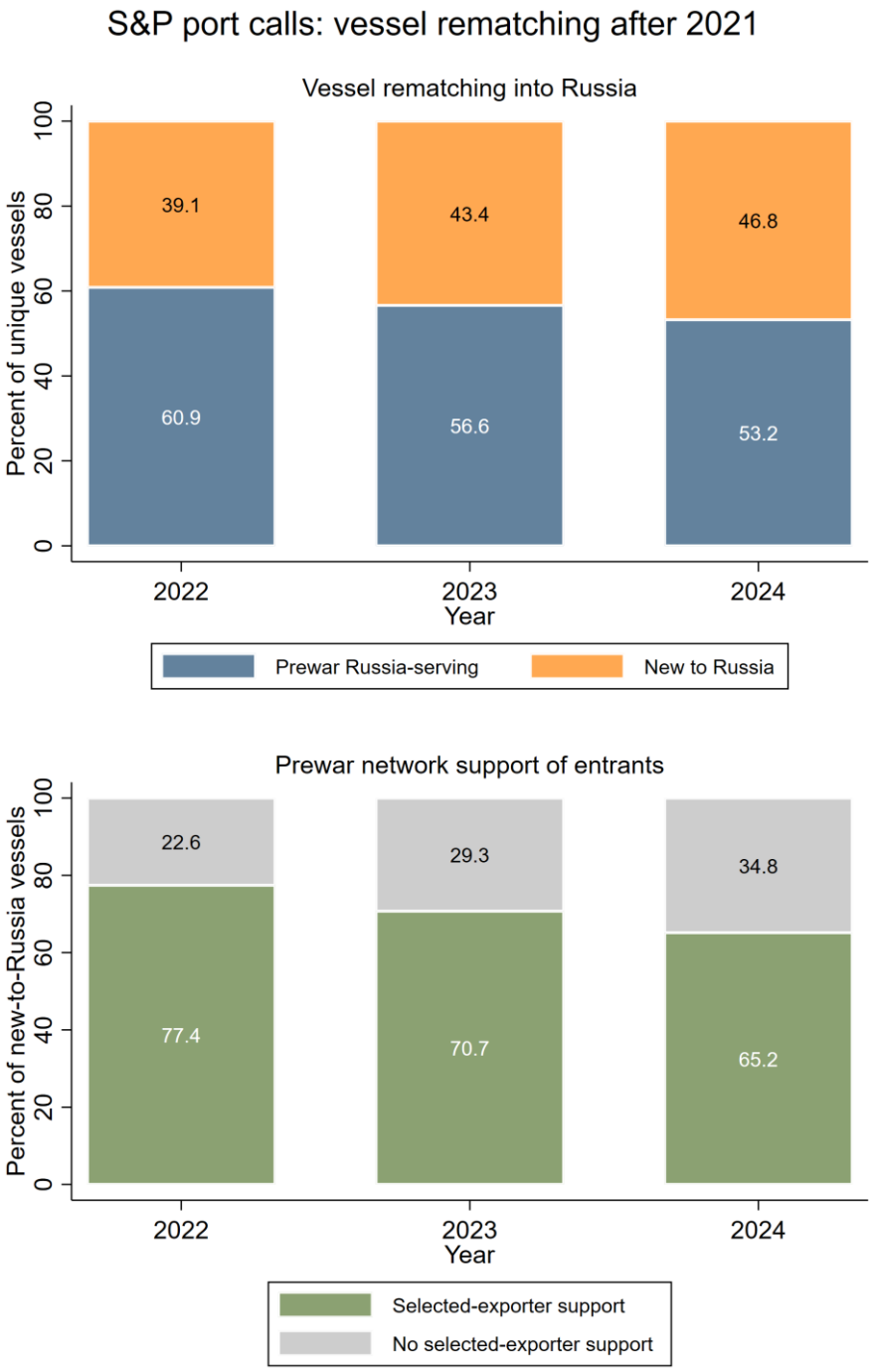
Notes: PORTSTAT measures observed grain throughput, whereas Kpler measures candidate voyage paths and route operations; the panels document why the two series need not move one-for-one.

Figure A7. S&P Route Length, Transit Time, and Survival



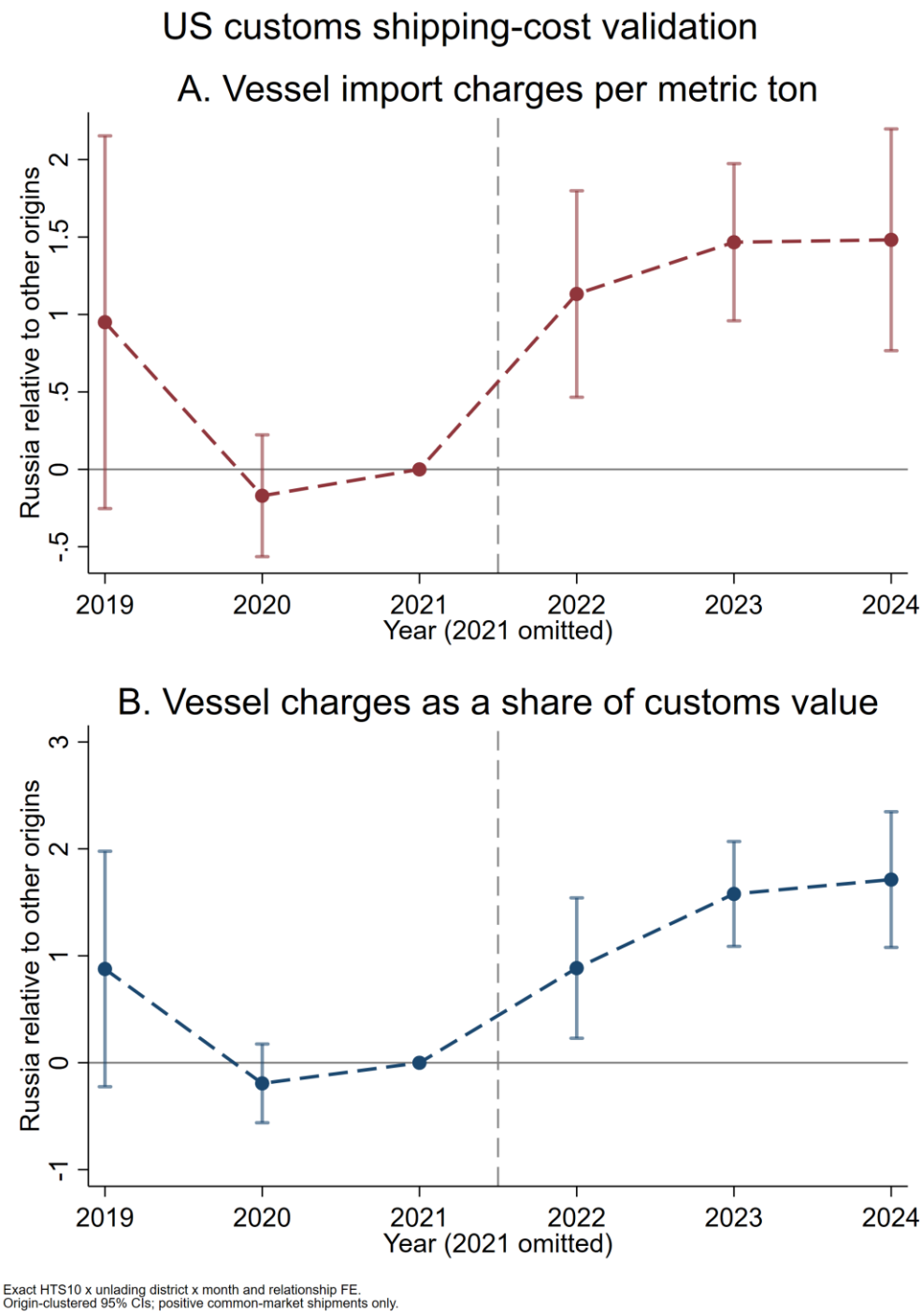
Notes: Route survival is shown both unweighted and weighted by 2021 leg activity, preserving the fixed prewar route support.

Figure A8. S&P Vessel Rematching after 2021



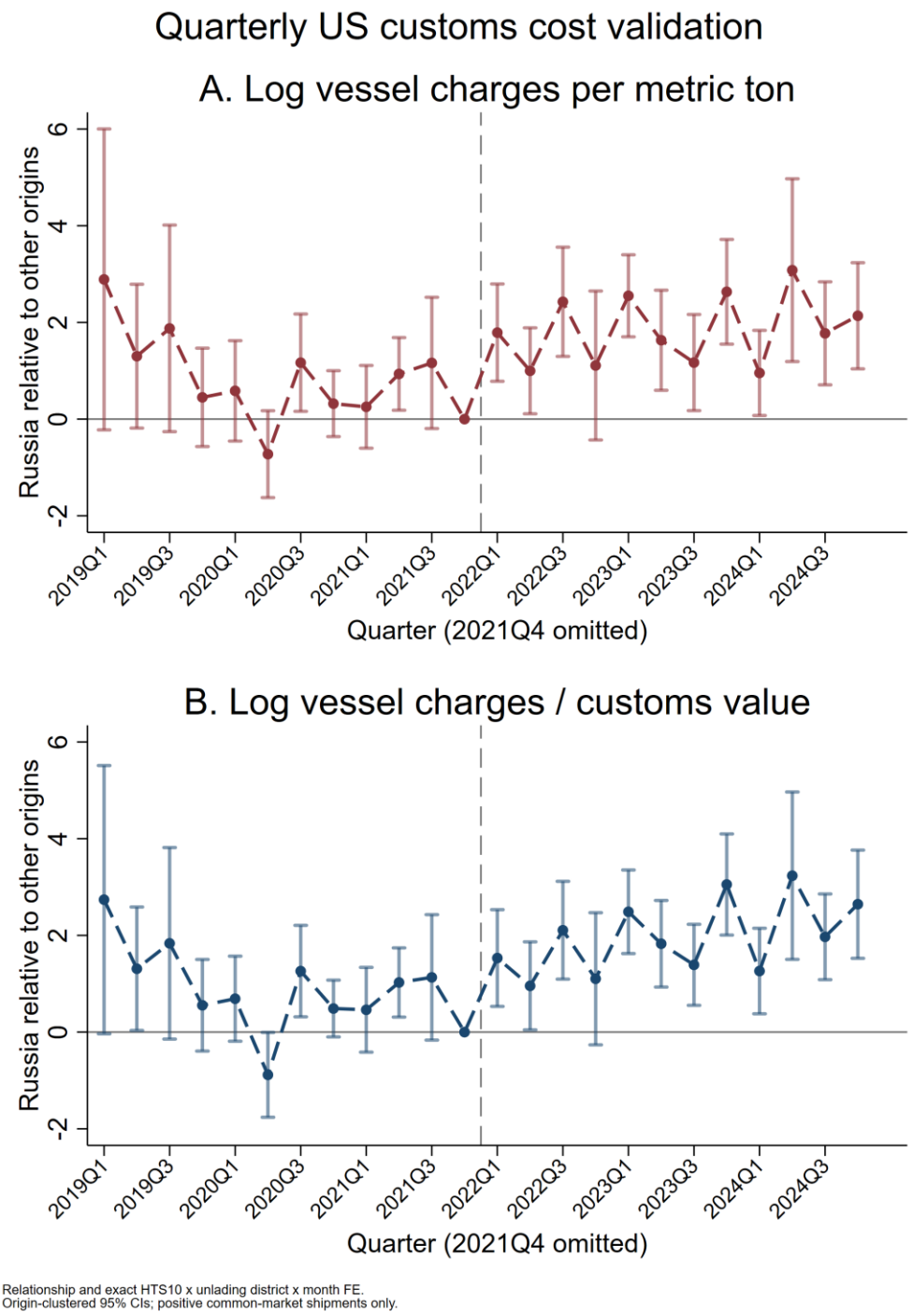
Notes: The first panel separates vessels that served Russia before 2022 from vessels newly matched to Russia; the second panel reports entrants' prewar support in selected exporter networks.

Figure A9. Annual U.S. Customs Transport-Cost Validation



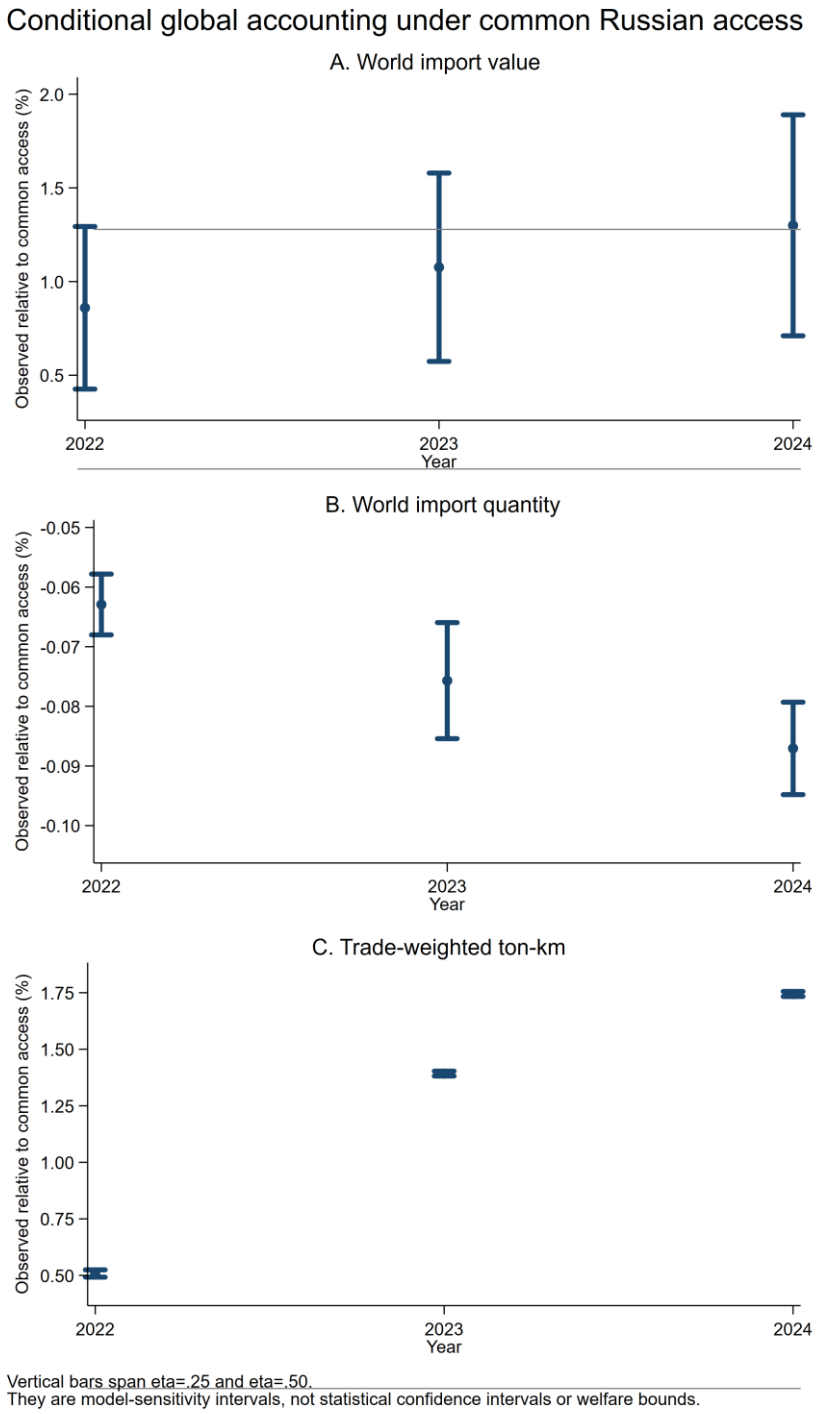
Notes: Annual U.S. vessel-import-charge outcomes provide a one-destination descriptive comparison. They do not identify the global destination-access coefficient.

Figure A10. Quarterly U.S. Customs Transport-Cost Stress Test



Notes: Quarterly specifications expose unfavorable pretrend sensitivity and therefore limit the external-cost evidence to appendix diagnostic.

Figure A11. Common-Access Counterfactual: Aggregates and Transport Resources



Notes: Annual fitted-access minus common-access accounting, relative to common access. Bars span demand-elasticity scenarios 0.25 and 0.50; they are not confidence intervals or welfare bounds. Quantity and ton-kilometers use baseline quantity support. Within-link distances are held fixed. See equations (10) and (16).