When a Port Disappears: How Trade Networks Rewire Around a Failed Node

Yuheng Zhao[1] **Yanan Jia**[2]

Draft for the NBER Economics of Transportation in the 21st Century meeting

September 2026

Abstract

What keeps trade moving when a major port suddenly disappears from the usable network? We study the 26 March 2024 collapse of Baltimore's Francis Scott Key Bridge, which suddenly removed normal deep-draft access; access returned in stages and the federal channel regained its original dimensions 76 days later. Linking U.S. customs records to Kpler cargo movements and S&P Global vessel calls, we identify how trade reattached to alternative ports. Per 10-percentage-point higher predetermined Baltimore exposure, destination-product export value fell by 0.222 IHS points at Baltimore and rose by 0.190 at other U.S. ports in the closure quarter; the total-U.S. estimate was -0.035 and imprecise. Cargo technology selected both the substitute port and the adjustment margin. Census and Kpler show coal and coke moving toward Virginia, while fixed pre-collapse container and vehicle fleets rematched disproportionately toward New York/New Jersey. Independent import relationships show the same temporary increase in alternative-port use, and the effects attenuate after channel access returned. A failed node can therefore generate severe local losses while the wider network reattaches much of its trade through cargo-specific matches among terminals, inland links, commercial relationships, and vessel services.

Keywords: ports; transportation networks; trade reallocation; supply-chain resilience; maritime shipping

JEL classifications: F14; L92; R41; R42

[1] School of Peace and Development, Renmin University of China, Beijing, China. Email: zhaoyuheng@ruc.edu.cn.

[2] School of Agricultural Economics and Rural Development, Renmin University of China, Beijing, China.

1. Introduction

The collapse of one port can look catastrophic locally and modest nationally, but that contrast does not explain how continuity is produced. Transportation infrastructure determines both the cost of ordinary trade and the options available when ordinary routes fail. Evidence from railroads and highways shows that transport links lower trade costs and change the level and composition of trade (Donaldson 2018; Duranton, Morrow, and Turner 2014), while quantitative spatial and shipping models trace how geography and network structure shape economic activity and endogenous transport costs (Allen and Arkolakis 2014, 2022; Wong 2022). Research on production networks separately shows how firm-level shocks propagate through specific input relationships and how endogenous sourcing choices can generate fragility (Barrot and Sauvagnat 2016; Carvalho et al. 2021; Elliott, Golub, and Leduc 2022). We connect these questions by asking how an established trade network reroutes flows and transport assets when a major node becomes unavailable without warning.

The collapse of Baltimore's Francis Scott Key Bridge creates a sharply timed transportation-network experiment. At about 1:29 a.m. on 26 March 2024, the containership Dali struck the bridge, and the resulting collapse obstructed the principal deepwater route between the Port of Baltimore and the Atlantic Ocean (National Transportation Safety Board 2025). Access returned in stages: a 400-foot-wide, 50-foot-deep limited channel opened on 21 May for all pre-collapse deep-draft commercial vessels, and the federal channel returned to its original 700-foot width and 50-foot depth on 10 June, 76 days after the collapse (U.S. Army Corps of Engineers 2024). We combine monthly U.S. Census port-product-country trade records with licensed Kpler cargo movements, licensed S&P Global vessel calls, Maryland Port Administration throughput, and official event records. These sources let us follow the response from destination-product flows to physical cargo and individual vessels.

The first result is a large spatial reallocation in the closure quarter. We fix exposure before the accident as Baltimore's 2019-2022 share of each destination-country by HS6 relationship's U.S. vessel exports. Per 10-percentage-point higher exposure, 2024Q2 export value falls by 0.222 IHS points at Baltimore and rises by 0.190 at other U.S. ports. The total-U.S. coefficient is -0.035, with a 95 percent confidence interval that includes zero. The national network therefore absorbed much of the disabled node's lost trade, although the estimates do not establish exact aggregate preservation.

The second result is that cargo technology selected both the substitute port and the economic object that moved. Exact Census accounting and independent Kpler records show large coal-and-coke movements from Baltimore toward Norfolk and other Virginia terminals. Vessel calls reveal a different path for scheduled and unitized cargo: among the fixed pre-collapse container fleet, 64 percent of vessels first observed at a preselected alternative appeared in New York/New Jersey, while direct dry-bulk vessel rematching to Virginia was uncommon. Bulk flows could be reassigned through rail, contracts, inventories, and different ships; container and vehicle services more often rematched existing vessels within scheduled networks.

The third result is that reattachment appears in an independent direction of trade and is concentrated in the closure. Import relationships with greater 2022 Baltimore exposure became 1.62 percentage points more likely per 10-

percentage-point exposure to use an alternative port in April-May 2024 relative to the same calendar months of 2023, and their alternative-port tonnage rose. High-frequency Baltimore calls collapsed immediately after 26 March, while the export and import reallocation effects attenuated after channel access returned. The common timing across different records makes a permanent shift in Baltimore demand an unlikely explanation.

The paper's first contribution is to use node failure to reveal effective transportation redundancy. Canonical infrastructure studies ask what a new link creates; removing an established link reveals which existing alternatives are operational when the network is under pressure. Ordinary traffic shares mix demand, prices, capacity, contracts, and inertia. The closure separates the traffic normally assigned to Baltimore from the trade that the wider network can absorb, complementing work on the trade and welfare effects of transportation infrastructure (Donaldson 2018; Allen and Arkolakis 2022).

The paper's second contribution is to make cargo heterogeneity central to port resilience. Hamano and Vermeulen (2020) show that alternative Japanese ports mitigated export losses after the Great East Japan Earthquake. For the Baltimore closure, Colazo (2026) documents gradual recovery in containerized import categories after physical channel restoration. We identify how the network reallocated trade during the outage across destination-product gateways, actual bulk cargo, and fixed container, vehicle, and dry-bulk fleets. Coal and coke moved mainly through Virginia without broad rematching of Baltimore's dry-bulk vessels, while container and vehicle assets rematched toward New York/New Jersey. Terminal technology, inland links, contracting, and scheduled vessel services therefore determine which redundancy is economically usable.

The paper's third contribution is to establish the reallocation at progressively more physical units of observation. Predetermined exposure and held-out diagnostics identify destination-product switching; exact accounting translates the gradients into tons; a same-calendar placebo reproduces the timing in imports; Kpler independently records the bulk cargo; and S&P Global follows fixed vessels. Following the cautions for continuous-treatment difference-in-differences, we interpret the coefficients as local exposure gradients rather than an unrestricted causal dose-response function (Callaway, Goodman-Bacon, and Sant'Anna, forthcoming). Agreement across these units shows how a network can stabilize aggregate flows by changing the ports, cargo paths, and transport assets that produce them.

The remainder of the paper proceeds from the outage to the mechanism of reattachment. Section 2 describes Baltimore's specialized cargo systems and the closure. Section 3 introduces the customs, cargo, and vessel data. Section 4 presents the exposure designs. Section 5 estimates reallocation across U.S. ports. Section 6 shows how the adjustment differs across cargo and vessel systems and validates it in inbound trade. Section 7 develops the implications for network resilience, and Section 8 concludes.

2. Institutional Setting and the Port-Access Shock

This section establishes why the bridge collapse isolates a transport-node interruption rather than a broad regional demand shock. Baltimore's terminals lie upstream from the Francis Scott Key Bridge, so the collapsed span and vessel obstructed ordinary deep-draft access to the public and private marine terminals inside the harbor (National

Transportation Safety Board 2025). The accident did not destroy the production facilities or foreign destinations represented in our customs relationships, and it did not close competing ports. The principal treatment was therefore a sudden increase from normal access cost to practical unavailability at one node of the national port network.

Baltimore was economically important because it specialized rather than because it dominated every cargo category. The port handled vehicles and roll-on/roll-off cargo, containers, general cargo, and large dry-bulk volumes including coal. Specialization makes substitution an empirical question: a nearby port may have physical space yet lack the terminals, rail connections, labor, contracts, or vessel services required by a particular shipment. The paper therefore does not define alternatives by distance alone. It observes which ports actually received exposed flows and which pre-collapse vessels appeared at a preselected set of candidate ports.

The event window separates the accident, the period without normal access, and the staged return of channel capacity. We treat 26 March as the start of the interruption, April-May as the two complete affected months, 21 May as the return of a 400-foot channel for all pre-collapse deep-draft commercial vessels, and 10 June as restoration of the federal channel's original dimensions (U.S. Army Corps of Engineers 2024). March is a partial-treatment month in the monthly import design, while 2024Q2 is the main affected quarter in the quarterly export design. Because usable access expanded in stages, we report high-frequency timing rather than impose one reopening date on every operational outcome.

[Figure 1 is about here]

3. Data and Measurement

This section combines five sources whose measurement differences make the common result more informative. U.S. Census customs records provide the population of port-product-country trade flows; Kpler measures reported cargo movements; S&P Global records vessel calls; the Maryland Port Administration measures official port throughput; and NTSB and U.S. Army Corps records fix event timing. No single source identifies all margins, so we assign each source a narrow role and never translate a call into tonnage or a customs relationship into a named buyer-supplier match.

The main U.S. Census export panel is monthly at the customs-district by HS6 product by destination-country level. We aggregate the public records to destination-country by HS6 relationships and separate value and metric tons shipped through Baltimore, through all other U.S. vessel-export ports, and through the United States in total. We inverse-hyperbolic-sine transform value in thousands of dollars and quantity in metric tons, preserving zero flows in the balanced panel. The main universe contains 2,622 relationships, 158 destinations, and 101 HS6 products over 2019Q1-2024Q4.

Eligibility is determined entirely with pre-collapse trade. A relationship enters if its total U.S. vessel-export value from 2019 through 2022 is at least $1 million and it is positive in at least 12 months. This rule prevents mechanically unstable exposure ratios from relationships that barely traded before the event. Among eligible relationships, 1,722 have positive Baltimore exposure and 1,009 have exposure of at least 10 percent. Mean

exposure is 19.3 percent, while the median is 3.2 percent, reflecting the concentration of Baltimore dependence in a subset of destination-product flows.

The independent U.S. Census import panel reverses the direction of trade and uses a different exposure year. We define each country-HS6 relationship's 2022 share of U.S. vessel imports entering through Baltimore, then estimate whether the relationship becomes active and how much it imports through alternative U.S. ports in 2024. Outcomes include alternative-port activity, import value, shipping weight, and total charges. Because the import design compares the 2024 event path with the same calendar months of 2023, it absorbs relationship-specific seasonality without borrowing the export sample's identifying variation.

Kpler provides actual dry-cargo records at prelisted Baltimore, Virginia, and other U.S. origin terminals. After removing exact duplicates and restricting classified products, the local extract contains 3,156 positive-ton records; all classified cargo is thermal coal, metallurgical coal, or coke, and 4.5 percent of tonnage has a missing product label. Kpler is used for cargo magnitude and weekly timing, not for customs value or complete buyer identity. The terminal list and cleaning rules were fixed before estimating closure-period changes.

S&P Global provides port calls and vessel characteristics from 2020 through 2025. We deduplicate calls by the provider's call identifier and classify cargo-vessel types into container, vehicle/Ro-Ro, dry bulk, and general or multipurpose cargo. The high-frequency series count trailing seven-day Baltimore arrivals. The rematching exercise freezes the vessel universe at cargo vessels observed in Baltimore from 30 January through 25 March 2024 and records the first subsequent call, from 26 March through 9 June, at Virginia, New York/New Jersey, or Philadelphia. A vessel not observed at these selected ports is labeled accordingly; it is not assumed inactive everywhere.

Maryland Port Administration throughput provides an official check on the immediate node-level outage. Monthly autos, containers, general cargo, and Ro-Ro throughput all fell sharply in April-May relative to their 2019-2023 calendar-month averages. These series verify the treatment but do not furnish a counterfactual for national trade, so they remain descriptive and appear in Figure A7 rather than as a main causal result.

The data architecture deliberately separates economic units. A destination-country by HS6 relationship is a trade-flow edge, a Kpler record is reported cargo, and an S&P observation is a vessel call. Convergence across these units supports a network-reallocation interpretation, but disagreement need not be an error: a cargo flow can move through a different port without the same vessel, and a vessel can call without carrying the product universe observed in customs. Table 1 records every headline variable, source, construction, and unit.

[Table 1 is about here]

4. Empirical Design

This section estimates how three port margins changed with predetermined Baltimore dependence after the unexpected access shock. A relationship is r = (d,h), joining destination country d to HS6 product h; k indexes exports through Baltimore (B), all other U.S. vessel ports (O), or the United States in total (U). The continuous-

exposure event study includes relationship, destination-by-quarter, and product-by-quarter fixed effects. These fixed effects absorb time-invariant relationship composition, destination-specific demand or policy shocks, and product-specific national shocks. Identification comes from differential changes across relationships within the absorbed destination and product environments as a function of Baltimore's pre-event share.

For relationship r and quarter t, let Baltimore value and U.S. value denote vessel-export value through Baltimore and through all U.S. ports, respectively. Using the fixed pre-event set P = {2019Q1,…,2022Q4}, we define predetermined Baltimore exposure as:

$$E_r \equiv \frac{\sum_{t\in\mathcal{P}} X_{rt}^{B}}{\sum_{t\in\mathcal{P}} X_{rt}^{U}}, \mathcal{P} = \{2019Q1,\ldots,2022Q4\} \quad (1)$$

Pooling four pre-event years reduces the influence of a single seasonal shipment, and the exposure window ends more than a year before the accident. We multiply the exposure measure by ten, so each reported coefficient corresponds to a 10-percentage-point higher pre-collapse Baltimore share. Because exposure is continuous and concentrated near zero, the estimand is a conditional exposure gradient; it is not an unrestricted nonlinear dose-response function.

For each value or quantity outcome and each port margin k, we estimate the following dynamic exposure-gradient specification:

$$y_{rq}^{k} = \alpha_r^k + \delta_{d(r)q}^{k} + \mu_{h(r)q}^{k} + \sum_{\ell\in\mathcal{Q}\setminus\{q_0\}} \beta_\ell^k (10E_r)\mathbf{1}\{q=\ell\} + \varepsilon_{rq}^{k}, k \in \{B, O, U\} \quad (2)$$

In equation (2), the first fixed-effect term absorbs time-invariant relationship composition, while the next two absorb destination-by-quarter and product-by-quarter shocks. The reference quarter is 2024Q1, the final complete quarter before the collapse. For each margin k, an event coefficient is the IHS-point change associated with a 10-percentage-point higher predetermined Baltimore share in quarter ℓ relative to that reference quarter. Standard errors are two-way clustered by destination country and HS6 product, allowing common shocks on both sides of the relationship network. The 2023 coefficients are held-out diagnostics because neither eligibility nor exposure uses 2023; the main figure shows this clean holdout and 2024 rather than treating exposure-construction years as untouched pretrends.

The identifying assumption is that more and less exposed relationships within the absorbed destination-product environments would have followed parallel changes after 2024Q1 absent the closure. This assumption is not testable, but the four held-out 2023 coefficients provide a direct diagnostic. Their joint p-values are 0.332 for Baltimore value, 0.251 for other-port value, and 0.802 for total-U.S. value; the corresponding quantity p-values are 0.369, 0.094, and 0.923. The marginal other-port quantity diagnostic is why quantity evidence is supporting rather than the sole headline.

We supplement the event study with three identification audits. First, a linear pretrend-adjusted comparison projects the held-out 2023 gradient into 2024Q2. Second, network-topology-preserving randomization inference shuffles exposure across observed destination-product edges within HS6 products. Third, Rambachan-Roth

bounds report how the 2024Q2 conclusion changes when post-event trend violations can be multiples of pre-event violations. These tests consistently distinguish the strong Baltimore and other-port margins from the weaker total-U.S. margin.

The independent import design uses a distinct relationship r = (o,h), joining origin country o to HS6 product h, and a predetermined 2022 import exposure. Let t index year-month, c(t) its calendar month, and a(t) its year. We partition the event year into S = {March, April-May, June-December} and estimate the same-calendar specification:

$$y_{rt} = \alpha_{r,c(t)} + \psi_{r,a(t)} + \lambda_t + \sum_{s\in\mathcal{S}} \sum_{a\in\{2023,2024\}} \theta_{sa}\,(10E_r^M)\mathbf{1}\{t \in s, a(t) = a\} + u_{rt}, \quad \pi_s \equiv \theta_{s,2024} - \theta_{s,2023}, s \in \{\text{March,April–May,June–December}\}. \tag{3}$$

In equation (3), the three fixed-effect blocks absorb relationship-specific calendar-month seasonality, relationship-by-year shifts, and shocks common to each year-month. The interaction coefficients measure the exposure gradient for each event period and year; the reported period contrast subtracts the same-calendar 2023 gradient from the 2024 gradient. The closure-period contrast therefore asks whether more exposed import relationships used alternative ports unusually more in April-May 2024 than the same exposure gradient would predict one year earlier. Standard errors are clustered by relationship. This is an independent direction-of-trade validation of port reassignment, not a replication of the export estimand.

The design's principal limitation is that exposure may correlate with unobserved relationship attributes that also shape 2024 adjustment. Destination-by-quarter and product-by-quarter fixed effects remove broad demand and supply shocks, but continuous exposure does not become randomized by construction. The unexpected timing, clean held-out period, collapse-and-reopening pattern, placebo designs, and cross-data agreement make the port-access interpretation persuasive; they do not turn the exercise into a randomized trial. We preserve this distinction throughout the paper.

5. Destination-Product Reallocation Across U.S. Ports

This section shows that the disabled node lost exposed trade while the rest of the U.S. port network gained much of it. The main result is a pair of large, opposite-signed port margins in the closure quarter and a much smaller total-U.S. point estimate. This pattern is the paper's empirical core because it distinguishes disappearance at Baltimore from disappearance from U.S. vessel trade.

Baltimore export value falls sharply with predetermined exposure in 2024Q2. The coefficient is -0.222 IHS points per 10-percentage-point exposure, with a standard error of 0.033 and a 95 percent interval from -0.287 to -0.157. The 2023 coefficients are small and jointly insignificant, and the 2024Q1 normalization is zero by construction. The estimate is therefore not a continuation of an obvious held-out trend.

Other U.S. ports gain almost simultaneously. The 2024Q2 other-port coefficient is 0.190 IHS points, with a standard error of 0.030 and a 95 percent interval from 0.131 to 0.248. Its timing is difficult to reconcile with a Baltimore-specific collapse in foreign demand: a demand shock to the same destination-product relationship

should ordinarily reduce, not increase, its use of other U.S. ports. The natural interpretation is spatial reassignment of the U.S. gateway.

The total-U.S. margin is much smaller but does not prove full preservation. Its 2024Q2 coefficient is -0.035 IHS points, with a standard error of 0.023 and a 95 percent interval from -0.080 to 0.009. The point estimate implies that most of the Baltimore decline was absorbed elsewhere, but the interval includes both zero and economically meaningful losses. We therefore say that substitution substantially narrowed the aggregate gap, not that the gap was exactly closed.

[Figure 2 is about here]

The quantity estimates reproduce the same ordering. Per 10-percentage-point exposure, Baltimore quantity falls by 0.155 IHS points and other-port quantity rises by 0.129 in 2024Q2; total U.S. quantity falls by 0.027, with its upper confidence bound approximately zero. Figure A1 reports the full quantity event study. Agreement between value and physical quantity makes a pure price-composition explanation unlikely, while the slightly weaker quantity diagnostics warrant the paper's emphasis on the common direction rather than identical magnitudes.

Linear-trend adjustment leaves the two port margins economically large. The adjusted 2024Q2 coefficients are -0.203 for Baltimore value and 0.185 for other-port value. The adjusted total-value coefficient is -0.029 and remains statistically indistinguishable from zero. Figure A2 displays the raw and adjusted estimates; the exercise shows that reasonable extrapolation of held-out gradients does not create the headline reallocation.

HonestDiD sensitivity reaches the same hierarchy of conclusions. Under relative-magnitude restrictions allowing post-event violations up to twice the largest pre-event violation, the Baltimore and other-port value intervals exclude zero, whereas the total-U.S. interval does not. Under smoothness restrictions, the Baltimore margins withstand larger deviations than the other-port value margin, and the total margin is fragile. Figures A3 and A4 report the sensitivity paths rather than a binary pass-fail label.

Network-preserving randomization inference rejects the view that the closure estimates are generic features of the observed destination-product graph. Exposure is permuted only across existing country-HS6 edges within each HS6, preserving product-level exposure distributions and network topology. The observed Baltimore and other-port estimates lie in the tails of the permutation distribution; Figure A5 reports the full exercise. This test addresses chance assignment within the observed graph, not omitted economic attributes of highly exposed edges.

The 2024Q3 and 2024Q4 paths suggest recovery with some residual differences. Baltimore's value gradient narrows from -0.222 in the closure quarter to -0.076 in 2024Q3 and -0.125 in 2024Q4, while the other-port value gradient falls to roughly 0.02. The asymmetry is consistent with resumption at Baltimore plus delayed or incomplete normalization, but later coefficients can reflect new shocks and contract timing. We therefore use post-reopening quarters to establish attenuation, not to estimate a permanent effect.

Table 2 summarizes the main and adjusted estimates alongside pretrend diagnostics. The important comparison is across margins: the failed node and its alternatives show precise opposite movements, whereas the national total

is estimated less precisely and much closer to zero. A narrative that reports only Baltimore would overstate destruction; a narrative that reports only the total point estimate would overstate seamless resilience.

[Table 2 is about here]

6. Cargo-Specific Reallocation Across Trade and Vessel Systems

This section establishes cargo technology as the organizing mechanism of network reattachment. Census and Kpler recover the same bulk movement toward Virginia, inbound customs relationships temporarily use alternative ports more, and fixed vessel fleets reveal a different path for scheduled and unitized cargo. The evidence spans different providers, trade directions, time frequencies, and physical units, yet it converges on a common result: coal, containers, and vehicles access different forms of redundancy.

Exact Census accounting first translates the exposure gradients into aggregate closure-period magnitudes. For the locked product universe, Baltimore vessel exports fell by 3.316 million metric tons in April-May 2024 relative to April-May 2023. Norfolk gained 2.126 million tons, and all other U.S. ports together gained 0.671 million. The United States therefore recorded a net decline of about 0.520 million tons in this accounting frame. The arithmetic shows large substitution and a remaining gap; it does not condition on exposure or control for other year-over-year shocks.

Kpler independently recovers the two largest bulk-cargo movements. Reported cargo at the prelisted Baltimore dry-bulk terminals fell by 3.341 million tons, while reported cargo at the Virginia terminals rose by 2.448 million. The source, terminal mapping, and cargo definition differ from the Census records, so exact equality is neither expected nor claimed. The close order of magnitude is nonetheless informative because a shared customs coding or value deflator cannot generate it.

[Figure 3 is about here]

Weekly Kpler data locate the bulk reallocation inside the closure window. Relative to the same ISO weeks of 2023, Baltimore cargo fell 72.8 percent during event weeks 0-10, Virginia cargo rose 14.6 percent, and other U.S. cargo rose 36.3 percent. Baltimore's share of three-group cargo fell 21.2 percentage points, while Virginia and other U.S. shares rose 9.4 and 11.8 points. A 2023 pseudo-event does not show a comparable Baltimore collapse. Figure A6 is descriptive because the weekly sample contains only coal, coke, and incomplete product labels; it is a timing validation, not a comprehensive trade estimator.

The inbound Census design reproduces temporary alternative-port use in a separate relationship universe. During April-May, a 10-percentage-point increase in 2022 Baltimore import exposure raises alternative-port route activity by 0.0162, with a standard error of 0.0040. Alternative-port import tonnage rises by 0.0947 IHS points, with a standard error of 0.0170. The corresponding March estimates are smaller, and the June-December differences are near zero. Thus, the effect appears during full closure rather than as a generic 2024 divergence.

[Figure 4 is about here]

Import value and total charges move with the physical import response, but unit-cost measures do not. During April-May, alternative-port import value rises by 0.244 IHS points and total charges rise by 0.171. By contrast, log cost per ton and the log charge share are imprecisely estimated near zero. The customs charge field is not a complete measure of handling, inland transport, demurrage, or inventory costs, so the null unit-cost result cannot establish costless substitution. It only prevents us from claiming a large average increase in the measured charge ratios.

S&P Global calls reveal a distinct rematching margin for scheduled and unitized cargo. Among 67 container vessels in the fixed pre-collapse Baltimore fleet, 43, or 64 percent, first appeared at New York/New Jersey among the selected alternatives during the closure; two appeared in Virginia and 22 appeared at none of the three selected alternatives. Vehicle/Ro-Ro vessels also show New York/New Jersey rematching, though less strongly. Direct dry-bulk vessel rematching is rare: five of 76 vessels first appear in Virginia, while 67 appear at no selected alternative.

[Figure 5 is about here]

The contrast between cargo and vessel evidence is economically useful rather than contradictory. Bulk cargo can move from Baltimore to Virginia through a new commercial match, rail routing, inventory release, or a vessel that was never in the fixed Baltimore fleet. Container liner services, by contrast, use scheduled networks in which the same ship may call at another established gateway. The adjustment object is therefore cargo-technology specific: one part of the network reallocates flows, another rematches assets.

High-frequency S&P calls also verify the abruptness and recovery of the node outage. Trailing seven-day Baltimore calls fell almost to zero across container/Ro-Ro/vehicle, dry-bulk, and general-cargo classes immediately after 26 March, remained depressed through much of the closure, and rose after channel access returned. Comparison-port call counts do not show a single clean offset because a call is not cargo tonnage and alternative capacity can be absorbed through larger loads, different terminals, or ports outside the four displayed groups.

Table 3 consolidates the cross-source magnitudes without pretending that they share a denominator. The table labels each unit explicitly: million tons for accounting, percentage points for route activity, IHS points for import tonnage, and shares of a fixed vessel fleet for rematching. This unit discipline is central to reproducibility and to the interpretation of apparent differences across providers.

[Table 3 is about here]

7. How Cargo-Specific Substitution Produces Network Resilience

This section develops the paper's central economic implication: effective transport redundancy is cargo specific. The failed node experienced a severe interruption, the remaining network absorbed much of the exposed flow, and different cargo systems used different operational margins. Resilience therefore resides in a portfolio of compatible terminals, inland connections, commercial arrangements, and vessel services across the network.

Node-level loss and network-level continuity are different economic objects. Baltimore's activity collapsed, yet other ports gained exposed trade and the national total moved much less. Ordinary traffic shares therefore conceal the option value of alternatives, while stable aggregate trade can conceal large local adjustment burdens.

Cargo heterogeneity reveals the architecture of usable redundancy. Norfolk and Virginia absorb bulk cargo, while New York/New Jersey is prominent in container and vehicle-vessel rematching. Bulk networks can reassign cargo through rail origins, terminals, contracts, inventories, and new ships; scheduled services can rematch existing assets across established gateways. This pattern accords with models in which hubs, scale, route balance, and matching frictions shape endogenous transport costs (Wong 2022; Ganapati, Wong, and Ziv 2024; Brancaccio, Kalouptsidi, and Papageorgiou 2020; Brancaccio et al. 2023).

Spatial continuity can carry adjustment costs even when aggregate flows remain comparatively stable. Rerouting may require longer inland hauls, additional handling, contract changes, inventory drawdowns, schedule disruption, or rents paid to scarce terminal and transport capacity. Posted wharfage and customs charge ratios cover only pieces of this generalized cost. Hummels and Schaur (2013) quantify transit time as an economically meaningful trade barrier, while Allen and Arkolakis (2022) show how a quantitative spatial model combined with link-level traffic and infrastructure data can map network changes into welfare. For Baltimore, a defensible welfare calculation would additionally require observed inland, handling, congestion, contract, and incidence data. The paper therefore treats its capacity and compatibility exercises as technical bounds rather than welfare estimates.

The policy implication is to evaluate resilience as a portfolio of interoperable, cargo-compatible alternatives. Rail connections, information systems, specialized terminals, emergency customs procedures, and temporary operating authority may raise the network's option value even when they carry little traffic in ordinary periods. The results identify the operating margins that investment appraisal and structural models should reproduce.

8. Conclusion

This paper identifies how U.S. trade reattached when a major port suddenly disappeared from the usable network. The Key Bridge collapse produced an immediate, near-complete interruption at Baltimore, while destination-product flows with greater predetermined exposure shifted toward other U.S. ports. The same temporary spatial response appears in outbound customs, inbound customs, actual cargo, and vessel-call records.

The central fact is rapid, cargo-specific reattachment. The two port-specific margins are large and precise, the national total moves much less, and the operational destination differs by cargo technology. These distinctions reconcile the visually dramatic failure of one node with the relative stability of a much larger trade network.

The broader implication is that transport resilience is an equilibrium property of a network, not a capacity statistic attached to one facility. A node can be indispensable locally yet substitutable nationally, and the substitute can depend on the cargo, vessel service, inland connection, and commercial relationship. Measuring only lost traffic at the failed node misses this adaptive margin; measuring only national totals misses the disruption that generated it.

Future work can price this reallocation by combining observed time, congestion, handling, inland transport, contract, and incidence data with a model that reproduces the documented port and cargo margins. The evidence here establishes the behavioral fact such a model must match: when normal access to Baltimore was abruptly removed and then restored in stages over 76 days, U.S. trade rewired quickly, unevenly, and through cargo-specific operating systems.

Conflict of Interest Statement

The authors used Kpler and S&P Global data accessed under paid or institutional licenses. Neither data provider had a role in the research design, analysis, interpretation, or writing. The authors report no other financial or nonfinancial interests related to this research.

Data and Code Availability

All code, public-source download scripts, design locks, validation logs, and derived nonconfidential tables will be archived with the paper. U.S. Census, NTSB, U.S. Army Corps of Engineers, Maryland Port Administration, and public facility records can be reacquired from their official sources. Licensed Kpler and S&P Global microdata cannot be redistributed, but the replication package will document required fields, filters, mappings, and checks so authorized users can reproduce the analysis. Confirm that the two licenses permit redistribution of every derived table and figure included in the submission.

References

Allen, Treb, and Costas Arkolakis. 2014. “Trade and the Topography of the Spatial Economy.” Quarterly Journal of Economics 129(3): 1085-1140.

Allen, Treb, and Costas Arkolakis. 2022. “The Welfare Effects of Transportation Infrastructure Improvements.” Review of Economic Studies 89(6): 2911-2957.

Barrot, Jean-Noël, and Julien Sauvagnat. 2016. “Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks.” Quarterly Journal of Economics 131(3): 1543-1592.

Brancaccio, Giulia, Myrto Kalouptsidi, and Theodore Papageorgiou. 2020. “Geography, Transportation, and Endogenous Trade Costs.” Econometrica 88(2): 657-691.

Brancaccio, Giulia, Myrto Kalouptsidi, Theodore Papageorgiou, and Nicola Rosaia. 2023. “Search Frictions and Efficiency in Decentralized Transport Markets.” Quarterly Journal of Economics 138(4): 2451-2503.

Callaway, Brantly, Andrew Goodman-Bacon, and Pedro H. C. Sant'Anna. Forthcoming. “Difference-in-Differences with a Continuous Treatment.” American Economic Review.

Carvalho, Vasco M., Makoto Nirei, Yukiko U. Saito, and Alireza Tahbaz-Salehi. 2021. “Supply Chain Disruptions: Evidence from the Great East Japan Earthquake.” Quarterly Journal of Economics 136(2): 1255-1321.

Colazo, Jorge. 2026. “Infrastructure Recovery and the Distribution of Trade Adjustment after the 2024 Baltimore Key Bridge Collapse.” SSRN working paper, posted July 15, 2026. https://doi.org/10.2139/ssrn.7120749.

Donaldson, Dave. 2018. “Railroads of the Raj: Estimating the Impact of Transportation Infrastructure.” American Economic Review 108(4-5): 899-934.

Duranton, Gilles, Peter M. Morrow, and Matthew A. Turner. 2014. “Roads and Trade: Evidence from the US.” Review of Economic Studies 81(2): 681-724.

Elliott, Matthew, Benjamin Golub, and Matthew V. Leduc. 2022. “Supply Network Formation and Fragility.” American Economic Review 112(8): 2701-2747.

Ganapati, Sharat, Woan Foong Wong, and Oren Ziv. 2024. “Entrepôt: Hubs, Scale, and Trade Costs.” American Economic Journal: Macroeconomics 16(4): 239-278.

Hamano, Masashige, and Wessel N. Vermeulen. 2020. “Natural Disasters and Trade: The Mitigating Impact of Port Substitution.” Journal of Economic Geography 20(3): 809-856.

Hummels, David L., and Georg Schaur. 2013. “Time as a Trade Barrier.” American Economic Review 103(7): 2935-2959.

National Transportation Safety Board. 2025. “Contact of Containership Dali with Francis Scott Key Bridge and Subsequent Bridge Collapse.” Marine Investigation Report MIR-25-40. Washington, DC.

Rambachan, Ashesh, and Jonathan Roth. 2023. “A More Credible Approach to Parallel Trends.” Review of Economic Studies 90(5): 2555-2591.

U.S. Army Corps of Engineers, Baltimore District. 2024. “U.S. Army Corps of Engineers Announces Full Restoration of Baltimore's Fort McHenry Federal Channel.” News release, June 10.

Wong, Woan Foong. 2022. “The Round Trip Effect: Endogenous Transport Costs and International Trade.” American Economic Journal: Applied Economics 14(4): 127-166.

Appendix A. Additional Design and Evidence

A1. Quantity outcomes

The quantity appendix verifies that physical volumes follow the same three-margin ordering as values. Baltimore quantity falls, other-port quantity rises, and total U.S. quantity changes much less in the closure quarter. The other-port quantity held-out diagnostic is less comfortable than its value analogue, so the appendix treats concordance across units as corroboration rather than an independent identification strategy (Figure A1).

A2. Pretrend and sensitivity analysis

The identification appendix reports adjusted rather than selectively favorable specifications. Figure A2 compares raw and linear-trend-adjusted 2024Q2 coefficients. Figures A3 and A4 report Rambachan-Roth relative-magnitude and smoothness sensitivity for the value outcomes. Figure A5 presents network-topology-preserving randomization inference. The common conclusion is that the two spatial margins are robust to materially larger deviations than the total-U.S. margin.

A3. High-frequency and official treatment validation

The timing appendix shows that the treatment is visible in both commercial and official records. Figure A6 reports Kpler's weekly coal-and-coke timing and shares. Figure A7 reports Maryland Port Administration monthly throughput by cargo category. Figure A8 reports the longer Baltimore port-share path for the locked product universe. None of these figures alone supplies the main counterfactual; together they verify timing, cargo composition, and recovery.

A4. Heterogeneity and partial cost evidence

The mechanism appendix distinguishes predetermined redundancy from measured generalized cost. Figure A9 reports heterogeneity by preexisting alternative-port support. Figure A10 reports incident-date posted wharfage for one standardized dry-bulk shipment. Posted schedules cover only selected port fees, and the heterogeneity design does not independently randomize network support. We therefore use both figures to discipline interpretation rather than to calculate welfare.

A5. Capacity and compatibility stress tests

The capacity appendix records failed and passed prediction gates before presenting any counterfactual. Public facility measures add little held-out predictive power, and leave-one-destination-out compatibility improves some equal-weight but not ton-weighted fit. Figure A11 reports the held-out diagnostics, and Figure A12 reports conditional technical bounds under fixed capacity, unavailable alternatives, and relaxed compatibility. These are scenario bounds conditional on the algorithm and are not behavioral or welfare counterfactuals.

Tables and Figures

Table 1. Variable definitions and data architecture

Variable	Definition	Source	Unit
Baltimore exposure (exports)	Baltimore share of a relationship's U.S. vessel-export value, 2019-2022; multiplied by 10 in regressions.	U.S. Census	Destination country x HS6
Baltimore exposure (imports)	Baltimore share of a relationship's U.S. vessel-import value in 2022; multiplied by 10.	U.S. Census	Origin country x HS6
Baltimore value / quantity	Quarterly vessel exports through Baltimore; IHS(value in $1,000) or IHS(metric tons).	U.S. Census	Relationship x quarter
Other-port value / quantity	Quarterly vessel exports through all U.S. ports other than Baltimore.	U.S. Census	Relationship x quarter
Total-U.S. value / quantity	Quarterly vessel exports through all U.S. ports, including Baltimore.	U.S. Census	Relationship x quarter
Alternative-port activity	Indicator that an import relationship is positive at a non-Baltimore vessel port in a month.	U.S. Census	Relationship x month
Alternative-port import tonnage	IHS shipping weight entering through non-Baltimore U.S. vessel ports.	U.S. Census	Relationship x month
Actual dry-cargo tons	Reported thermal coal, metallurgical coal, and coke cargo after exact-duplicate removal.	Kpler	Terminal x movement
Port call	Deduplicated arrival-to-sail call identifier; calls are never converted into tonnage.	S&P Global	Vessel x port call
First selected alternative	First call at Virginia, New York/New Jersey, or Philadelphia during 26 Mar-9 Jun by the fixed pre-collapse Baltimore fleet.	S&P Global	Vessel
Official throughput	Monthly autos, containers, general cargo, and Ro-Ro handled at Baltimore.	Maryland Port Administration	Cargo class x month

Notes: IHS denotes the inverse hyperbolic sine. A relationship is a country-HS6 trade-flow edge, not a named buyer-supplier pair.

Table 2. Port reallocation in the closure quarter

	Baltimore value	Other-port value	Total U.S. value	Baltimore quantity	Other-port quantity	Total U.S. quantity
2024Q2 estimate	-0.222***	0.190***	-0.035	-0.155***	0.129***	-0.027*
Standard error	(0.033)	(0.030)	(0.023)	(0.024)	(0.020)	(0.014)
95% confidence interval	[-0.287,-0.157]	[0.131,0.248]	[-0.080,0.009]	[-0.203,-0.108]	[0.090,0.167]	[-0.056,0.001]
Held-out 2023 joint p-value	0.332	0.251	0.802	0.369	0.094	0.923
Linear-trend-adjusted estimate	-0.203***	0.185***	-0.029	-0.145***	0.125***	-0.026**
Relationships	2,622	2,622	2,622	2,622	2,622	2,622

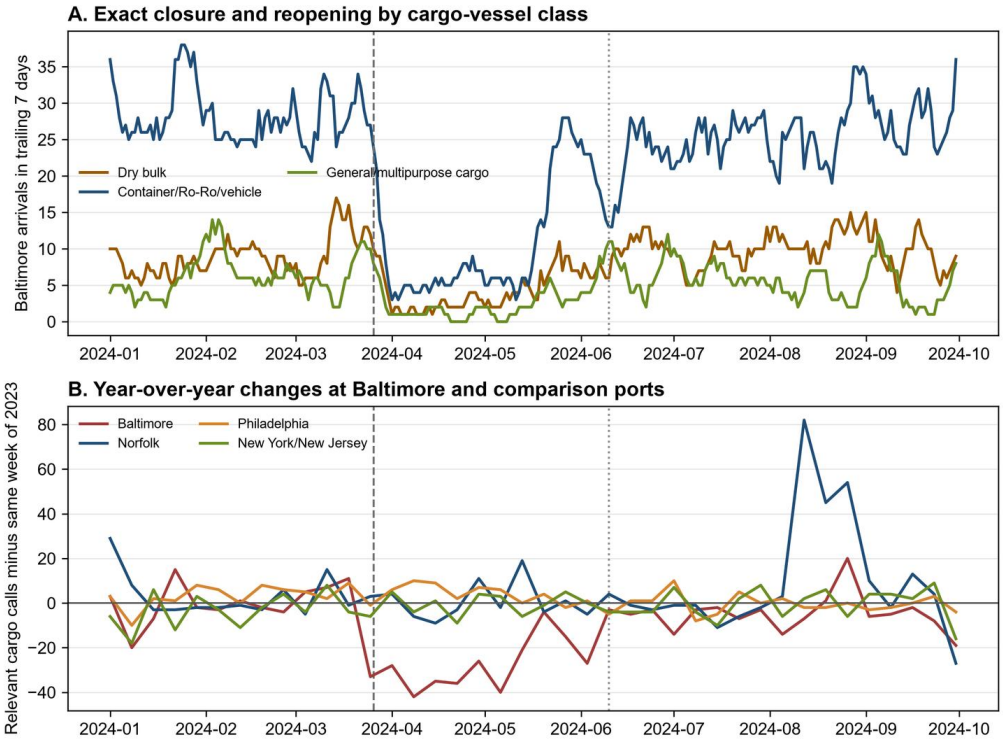
Notes: Coefficients are IHS points per 10-percentage-point higher 2019-2022 Baltimore exposure. The omitted quarter is 2024Q1. All models include relationship, destination-country-by-quarter, and HS6-by-quarter fixed effects. Standard errors are two-way clustered by destination country and HS6. Trend-adjusted intervals are reported in the appendix. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3. Independent validation and operational magnitudes

Evidence	Outcome / unit	Estimate	Uncertainty or comparator
Census export accounting	Baltimore, Apr-May 2024 minus 2023 (million tons)	-3.316	Norfolk +2.126; other U.S. +0.671
Kpler dry cargo	Baltimore, Apr-May 2024 minus 2023 (million tons)	-3.341	Virginia +2.448
Inbound Census DiD	Alternative-port route active, closure	0.0162***	SE 0.0040
Inbound Census DiD	IHS alternative-port tonnage, closure	0.0947***	SE 0.0170
Inbound Census DiD	IHS alternative-port value, closure	0.2441***	SE 0.0522
Inbound Census DiD	Log cost per ton, closure	0.0144	SE 0.0262; not significant
S&P fixed fleet	Container vessels first at New York/New Jersey	43 of 67	64.2% of locked vessels
S&P fixed fleet	Dry-bulk vessels first at Virginia	5 of 76	6.6%; cargo reallocation uses other vessels/margins

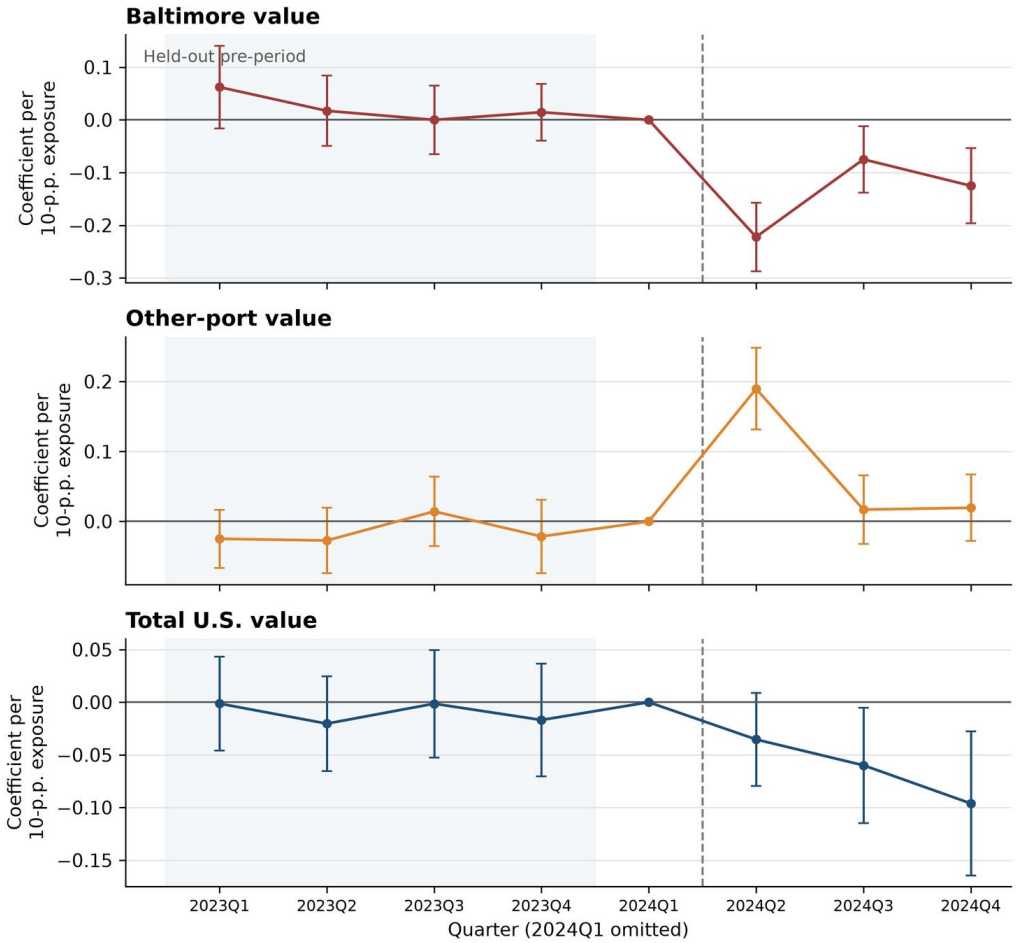
Notes: Accounting changes compare April-May 2024 with April-May 2023 and are descriptive. Inbound coefficients are 2024 event interactions minus the same-calendar 2023 interactions per 10-percentage-point 2022 Baltimore exposure, with relationship-clustered standard errors. Vessel shares use a pre-collapse fixed fleet and a preselected alternative-port set. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Figure 1. High-frequency vessel-call response around the Key Bridge collapse



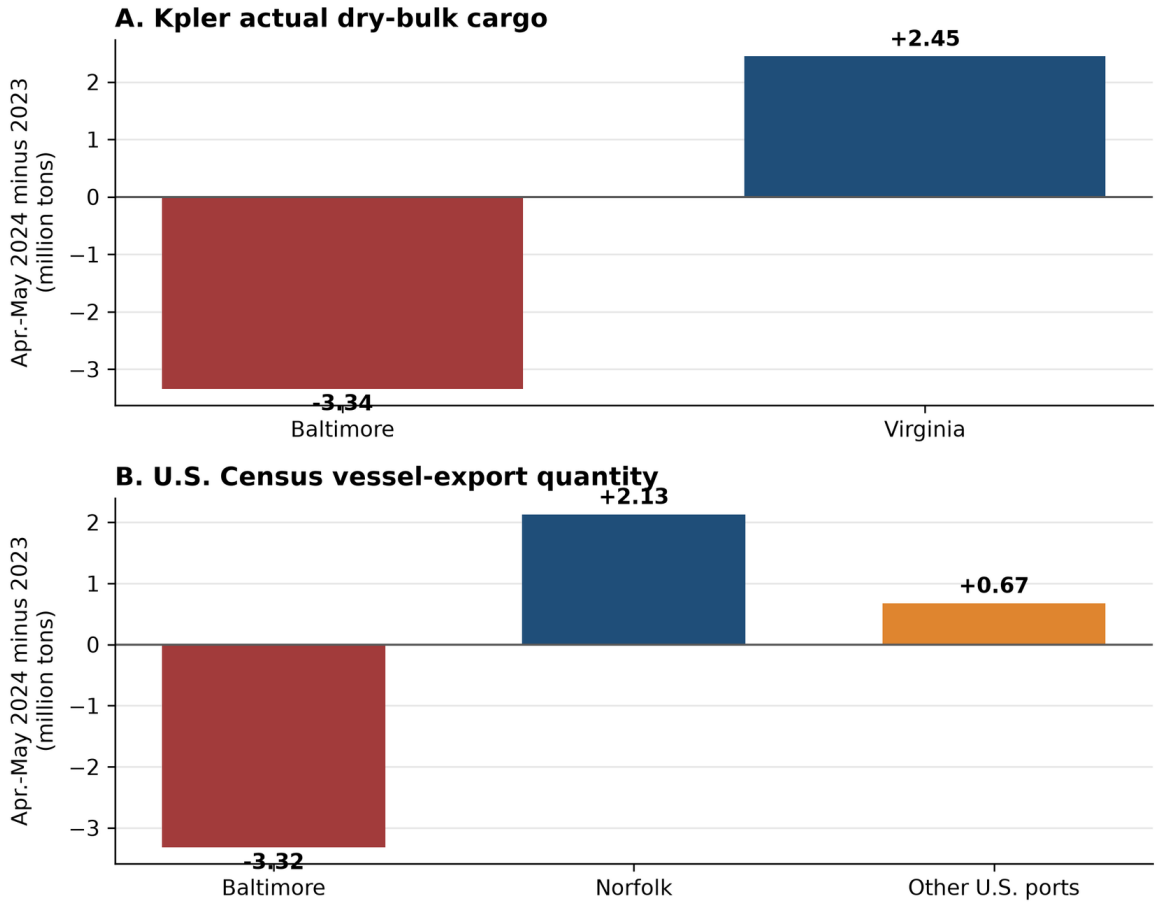
Notes: purchased S&P port calls, deduplicated by call ID. The comparison-port series do not show broad contemporaneous increases during the closure; port calls are not cargo tonnage and Panel B is descriptive.

Figure 2. Exposed export relationships shifted from Baltimore to other U.S. ports: values



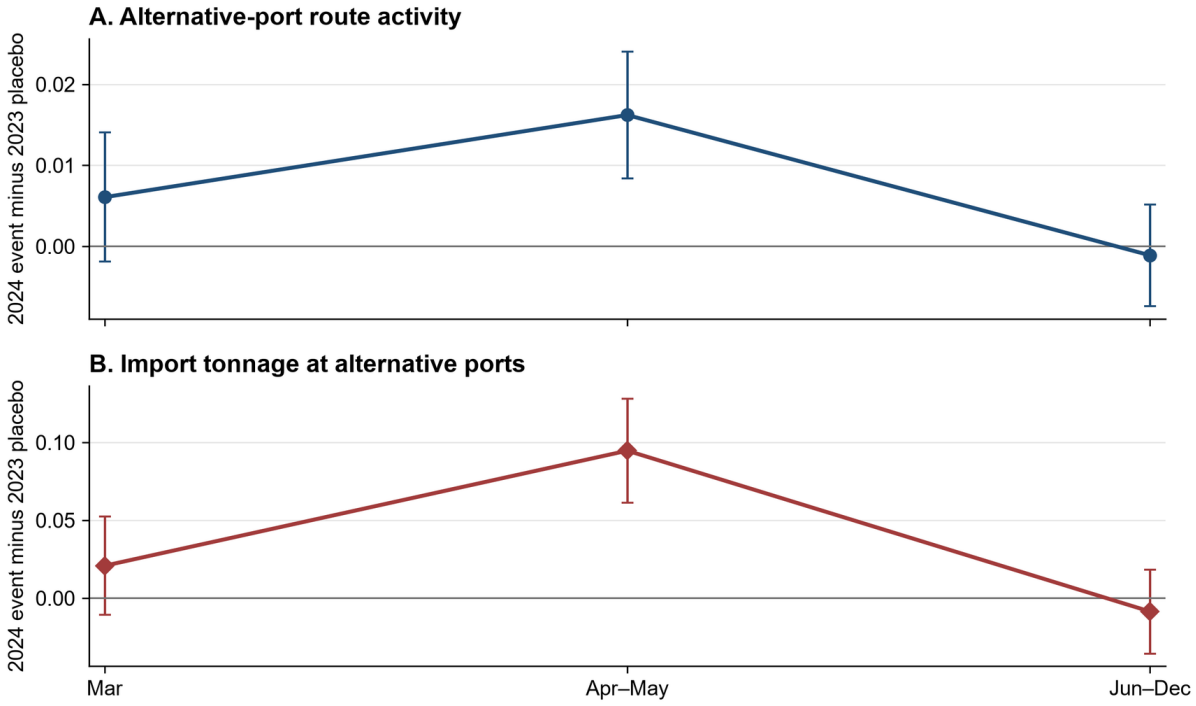
Notes: exposure is the 2019–2022 Baltimore share of each country–HS6 pair's U.S. vessel exports. Only the 2023 held-out pre-period and 2024 are shown. Relationship, country-by-quarter, and HS6-by-quarter fixed effects; 95% intervals are two-way clustered by destination country and HS6. The dashed line marks the bridge collapse/2024Q2 closure quarter. The total-U.S. panel is reported without interpreting a confidence interval that contains zero as full preservation.

Figure 3. Two independent cargo datasets recover the same port reallocation



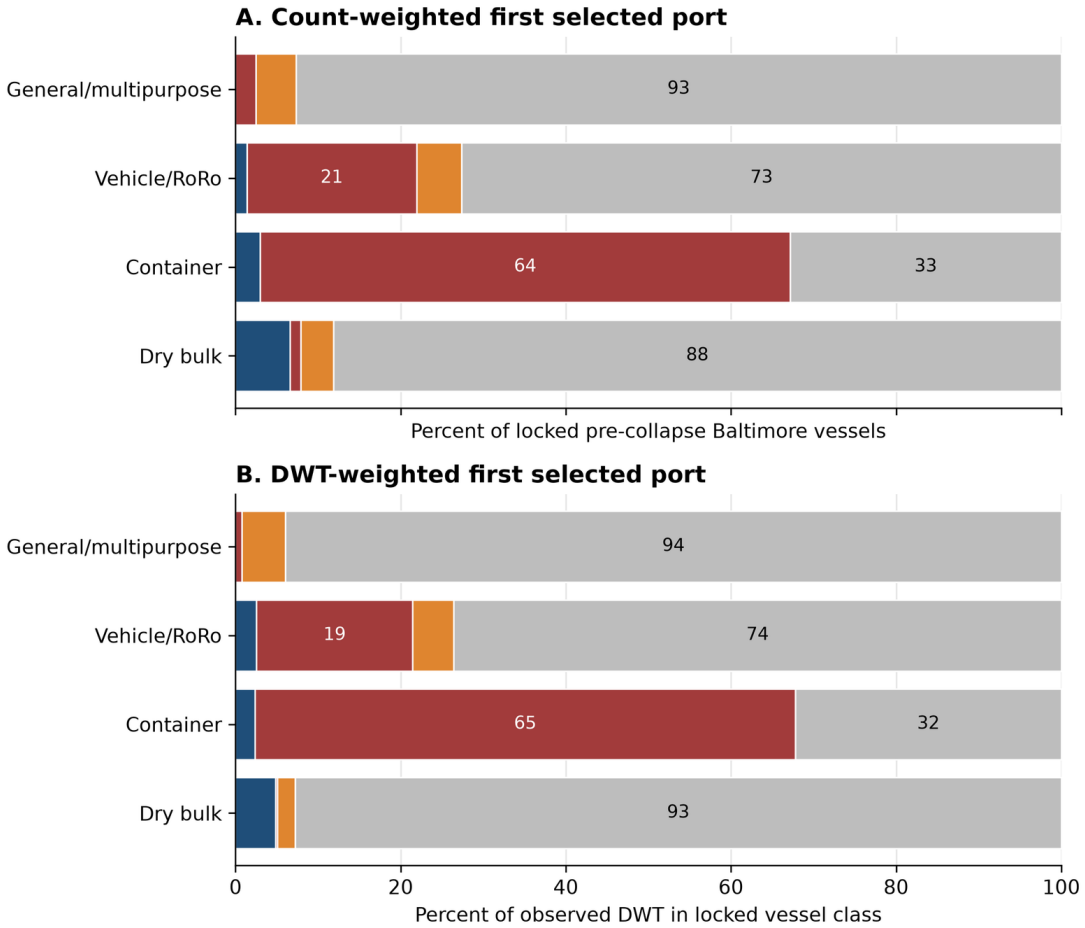
Notes: differences compare April-May 2024 with April-May 2023. Kpler measures reported cargo at the six prelisted dry-bulk terminals. Census measures metric tons for the prelocked HS6 product universe at customs districts. Similar magnitudes are a cross-provider validation, not a shipment-level match.

Figure 4. Baltimore closure effect net of the same-calendar 2023 placebo



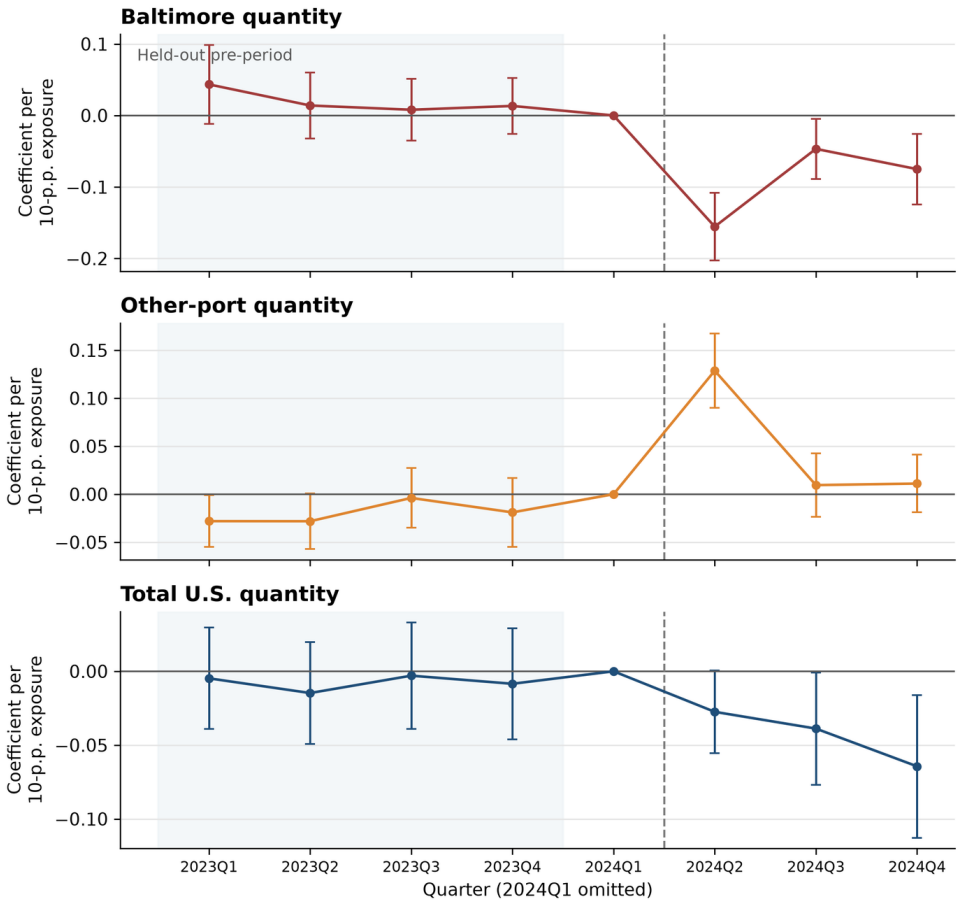
Notes: 2022 Baltimore exposure; relationship × calendar-month, relationship × year, and year-month fixed effects. Whiskers are relationship-clustered 95% confidence intervals.

Figure 5. Cargo vessels serving Baltimore rematched differently by vessel class



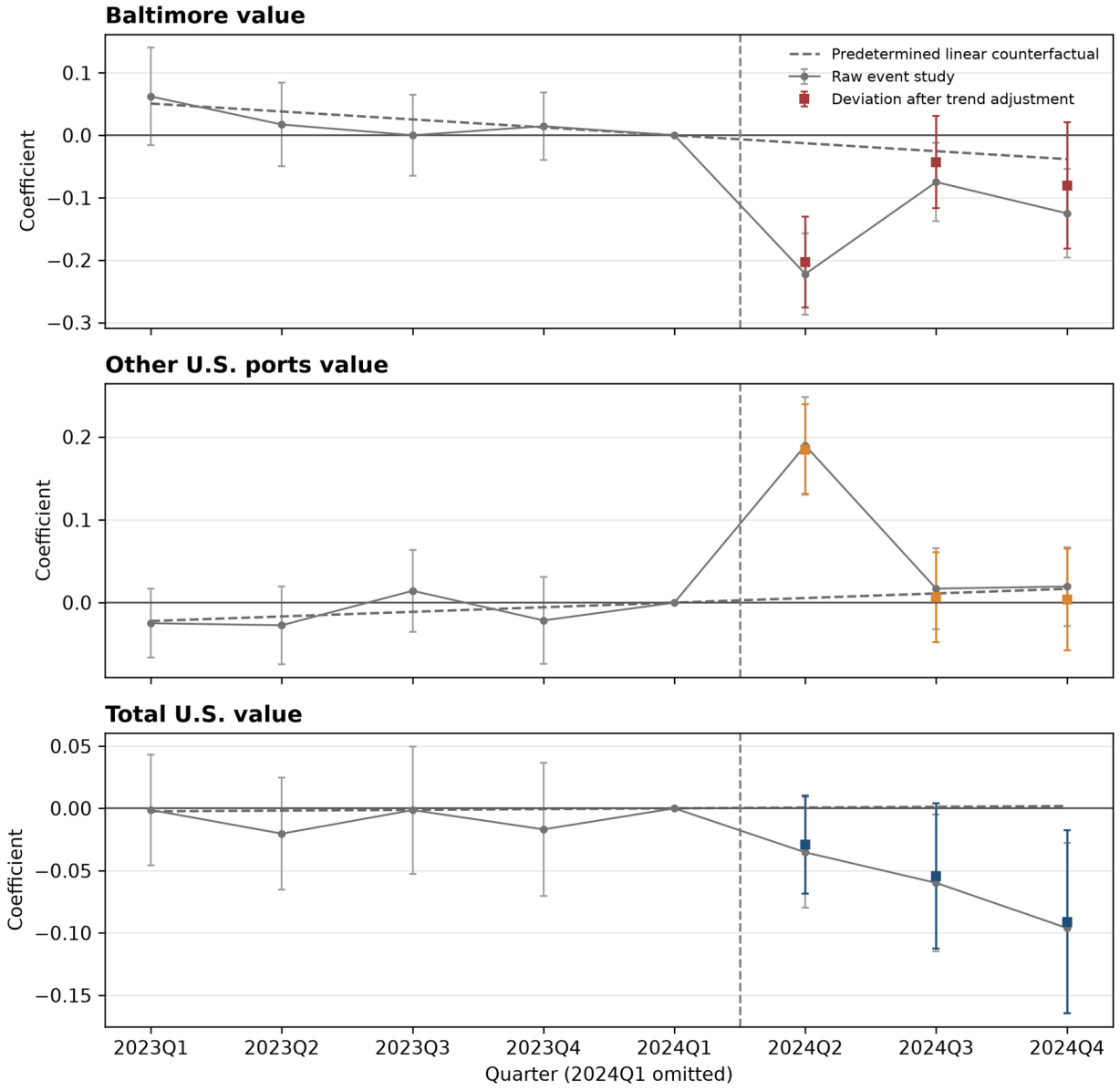
Notes: universe fixed before the collapse: all cargo vessels calling Baltimore from Jan. 30 to Mar. 25, 2024. Ports are the first call from Mar. 26 to June 9 among Virginia, New York/New Jersey, and Philadelphia. The residual category does not imply inactivity outside these selected comparison ports. DWT uses Kpler's metric-ton vessel register when available and USCG PSIX otherwise; missing DWT remains missing.

Figure A1. Exposed export relationships shifted from Baltimore to other U.S. ports: quantities



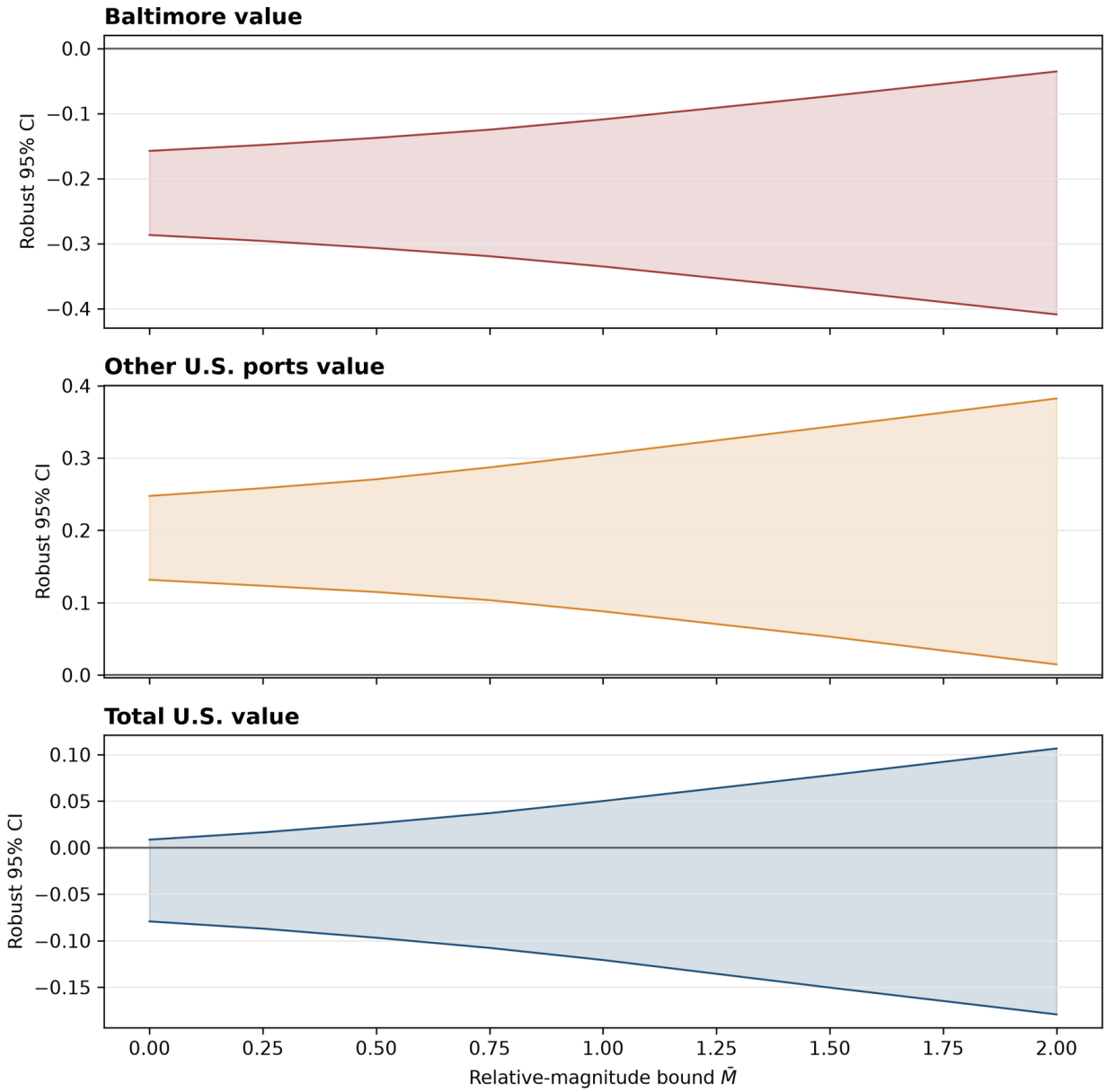
Notes: exposure is the 2019–2022 Baltimore share of each country–HS6 pair's U.S. vessel exports. Only the 2023 held-out pre-period and 2024 are shown. Relationship, country-by-quarter, and HS6-by-quarter fixed effects; 95% intervals are two-way clustered by destination country and HS6. The dashed line marks the bridge collapse/2024Q2 closure quarter. The total-U.S. panel is reported without interpreting a confidence interval that contains zero as full preservation.

Figure A2. Clean-window linear-pretrend audit: values



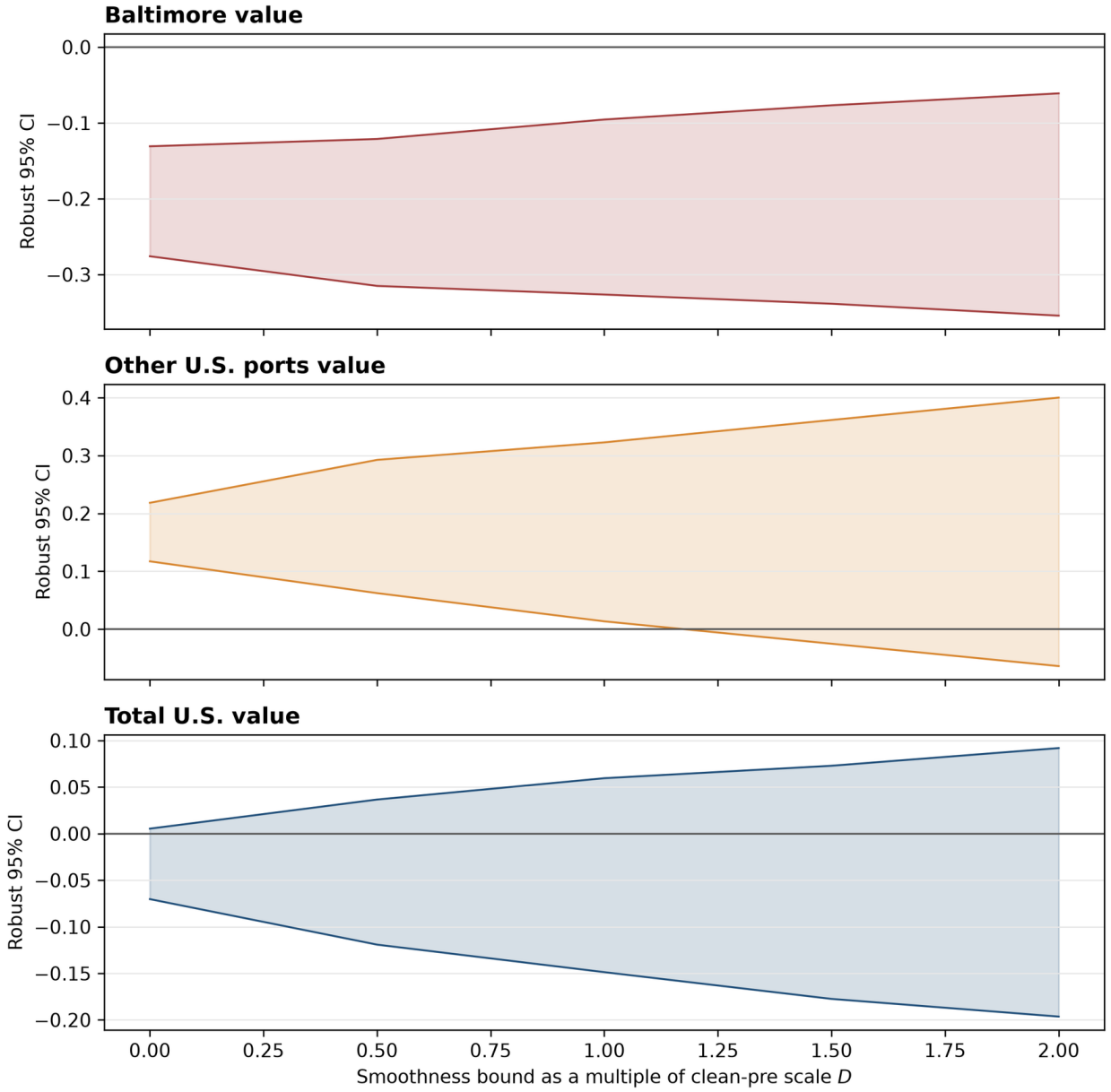
Notes: the dashed sloped line is estimated only from 2023Q1-2024Q1. Squares report 2024Q2-Q4 deviations from that fixed linear counterfactual. Fixed effects and two-way clustering match the locked main design.

Figure A3. HonestDID sensitivity: relative-magnitude redistributions



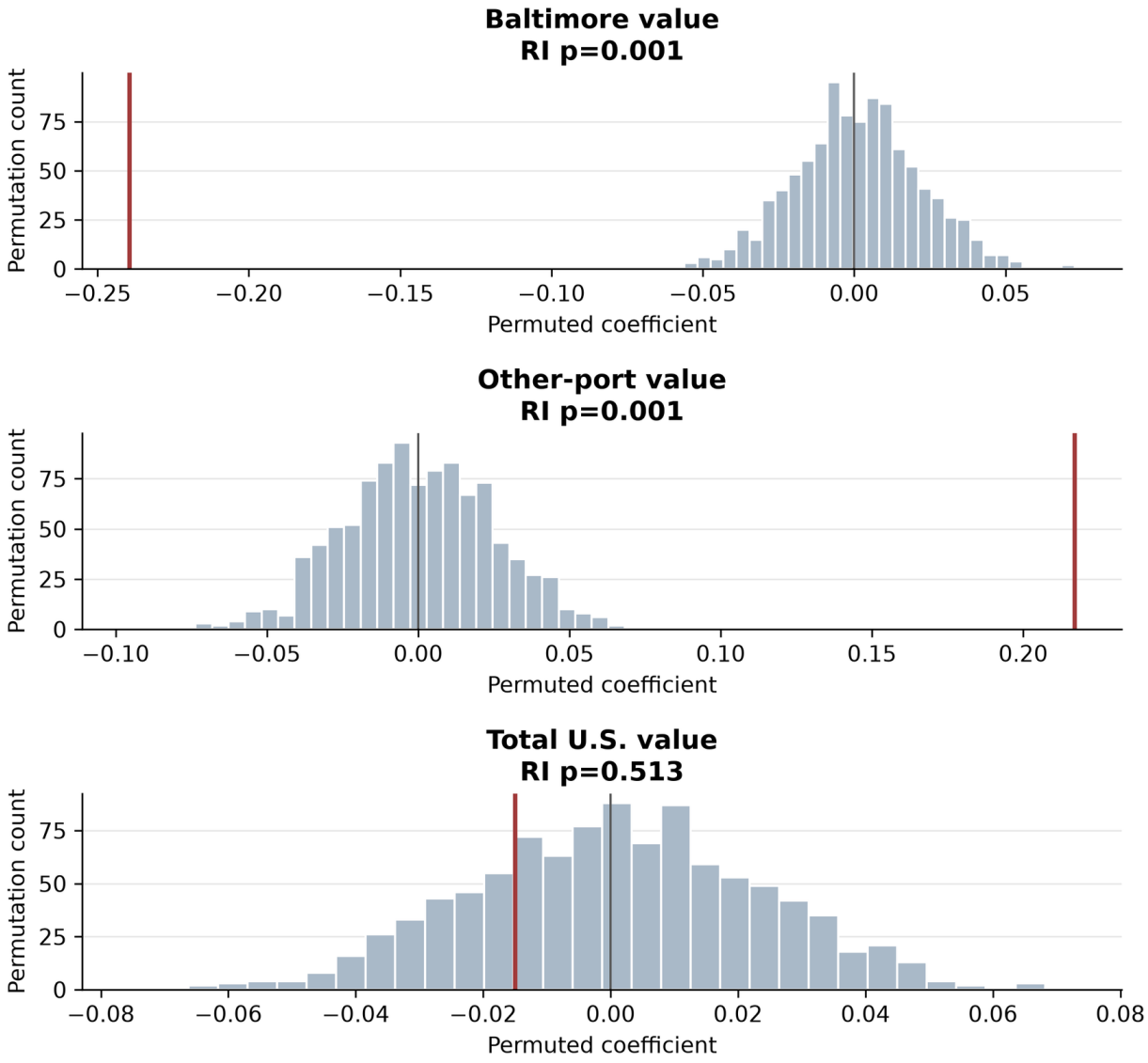
Notes: The target is the 2024Q2 coefficient. M-bar bounds post-treatment trend violations relative to the largest clean pre-period violation. Event-study covariance is two-way clustered by country and HS6.

Figure A4. HonestDID sensitivity: smoothness restrictions



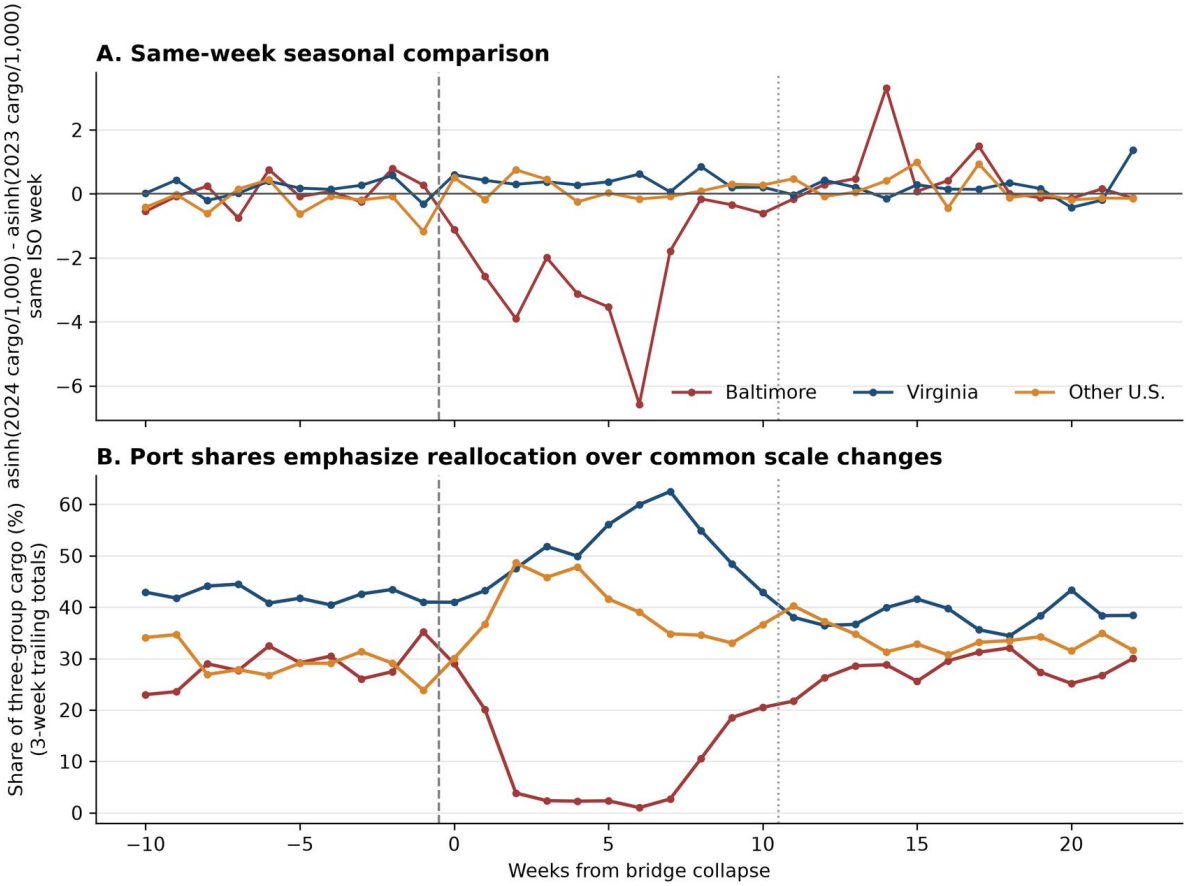
Notes: The target is the 2024Q2 coefficient. D is the maximum absolute second difference among 2023Q1-2023Q4 event-study coefficients, fixed separately by outcome before the sensitivity calculation. Event-study covariance is two-way clustered by country and HS6.

Figure A5. Network-topology-preserving randomization inference



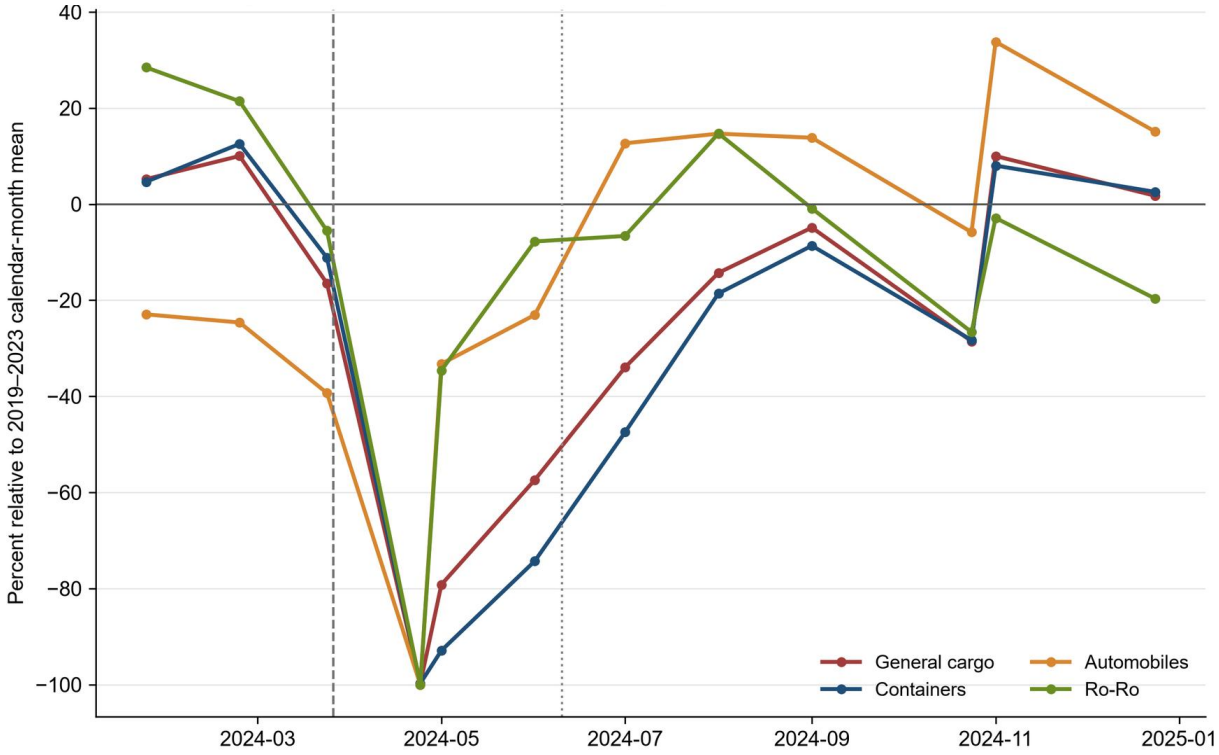
Notes: exposure is shuffled only across observed country-HS6 edges within each HS6. Product-specific exposure distributions and the eligible network topology remain fixed.

Figure A6. Kpler weekly cargo: seasonal and share-based validation



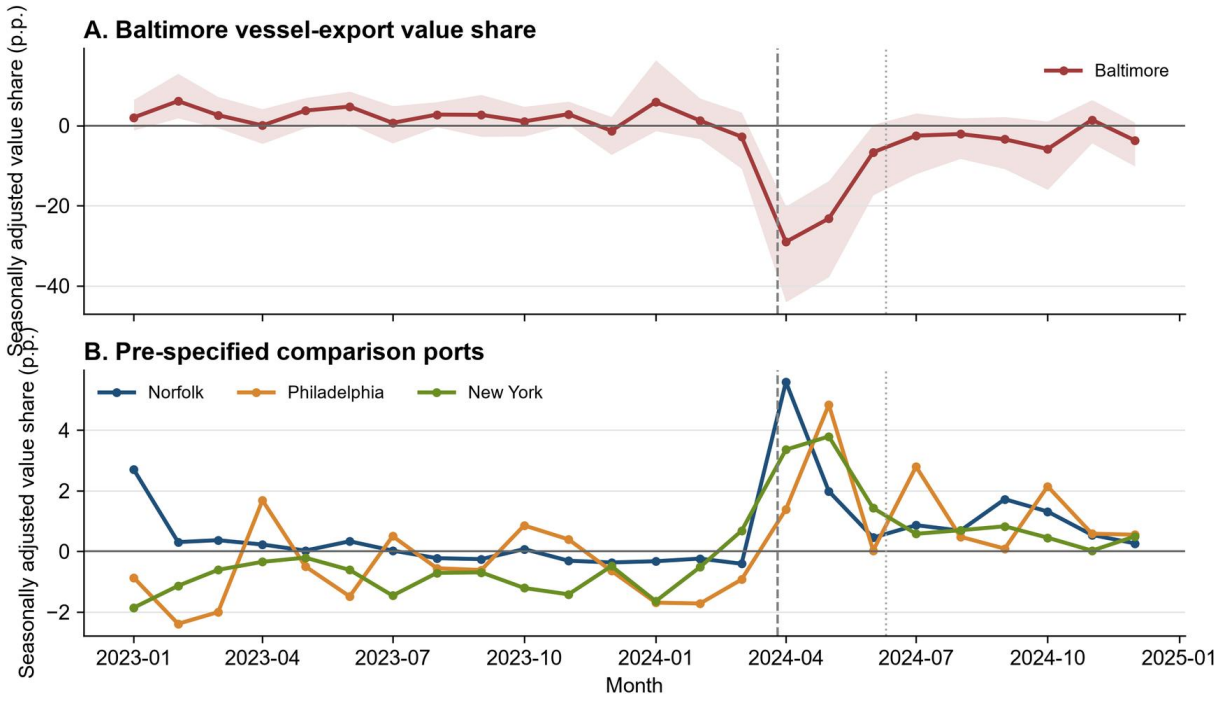
Notes: Kpler Dry cargo at the prelisted Baltimore, Virginia, and Other U.S. origin groups; exact duplicate rows removed. Panel A matches each 2024 week to the same ISO week in 2023 and starts at event week -10 because the cached 2023 extract begins 11 January. Panel B divides each port's backward-looking three-week cargo sum by the corresponding sum across the three groups. Dashed and dotted lines mark the collapse and full-channel reopening. All classified products are thermal coal, metallurgical coal, or coke; 4.5% of tons have missing product labels. Descriptive timing only.

Figure A7. Official Maryland Port Administration throughput



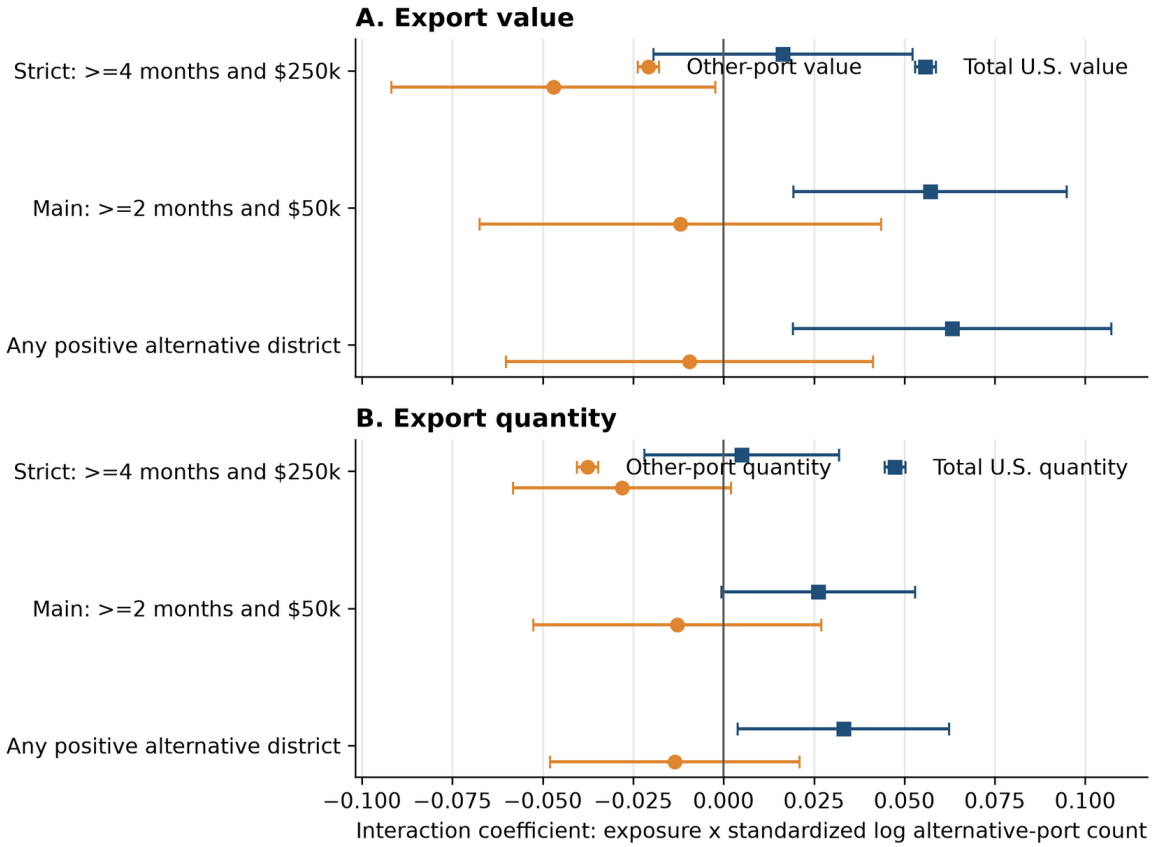
Notes: Official MPA monthly general-cargo series. The dashed line marks the bridge collapse; the dotted line marks full federal-channel reopening. The comparison is descriptive operational validation.

Figure A8. Descriptive monthly port-share paths around the Key Bridge collapse



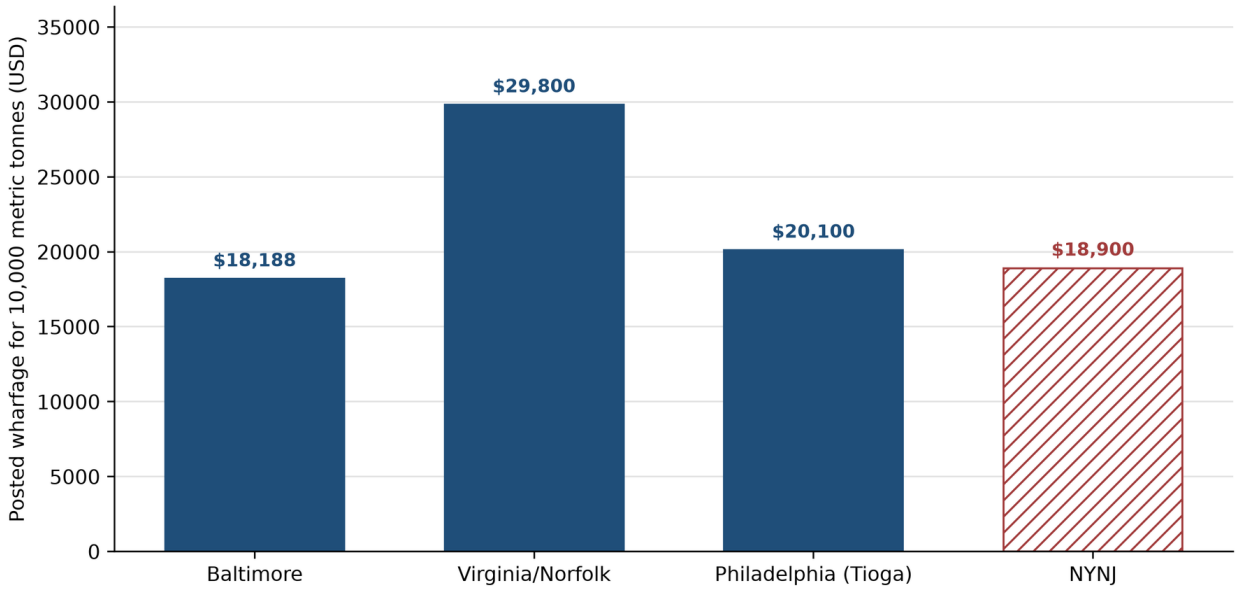
Notes: The 101-HS6 set and product weights are fixed using 2019–2023 Baltimore export values. Seasonality is the 2019–2023 product × port-group calendar-month mean. Intervals resample products; the figure is not a causal estimate of a one-port shock.

Figure A9. Does pre-existing port redundancy preserve exposed trade?



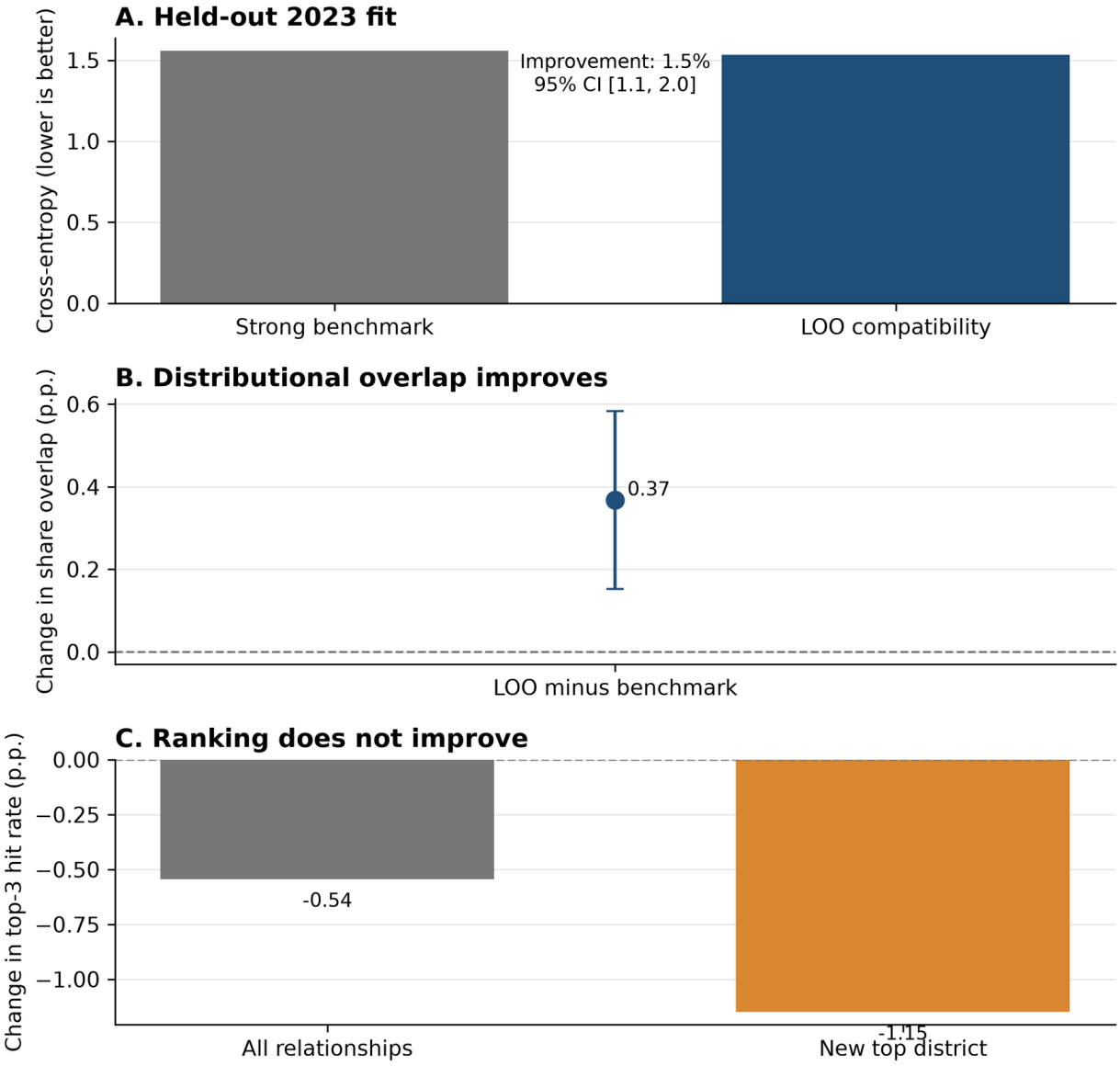
Notes: outcomes are 2024Q2 minus 2023Q2. Exposure and alternative-port counts use 2019-2022 only. Regressions include exposure, standardized log alternative-port count, their interaction, destination-country FE, and HS6 FE. 95% intervals are two-way clustered by country and HS6. Heterogeneity is predetermined but not a causal return to adding a port.

Figure A10. Incident-date posted wharfage benchmark for a fixed dry-bulk load



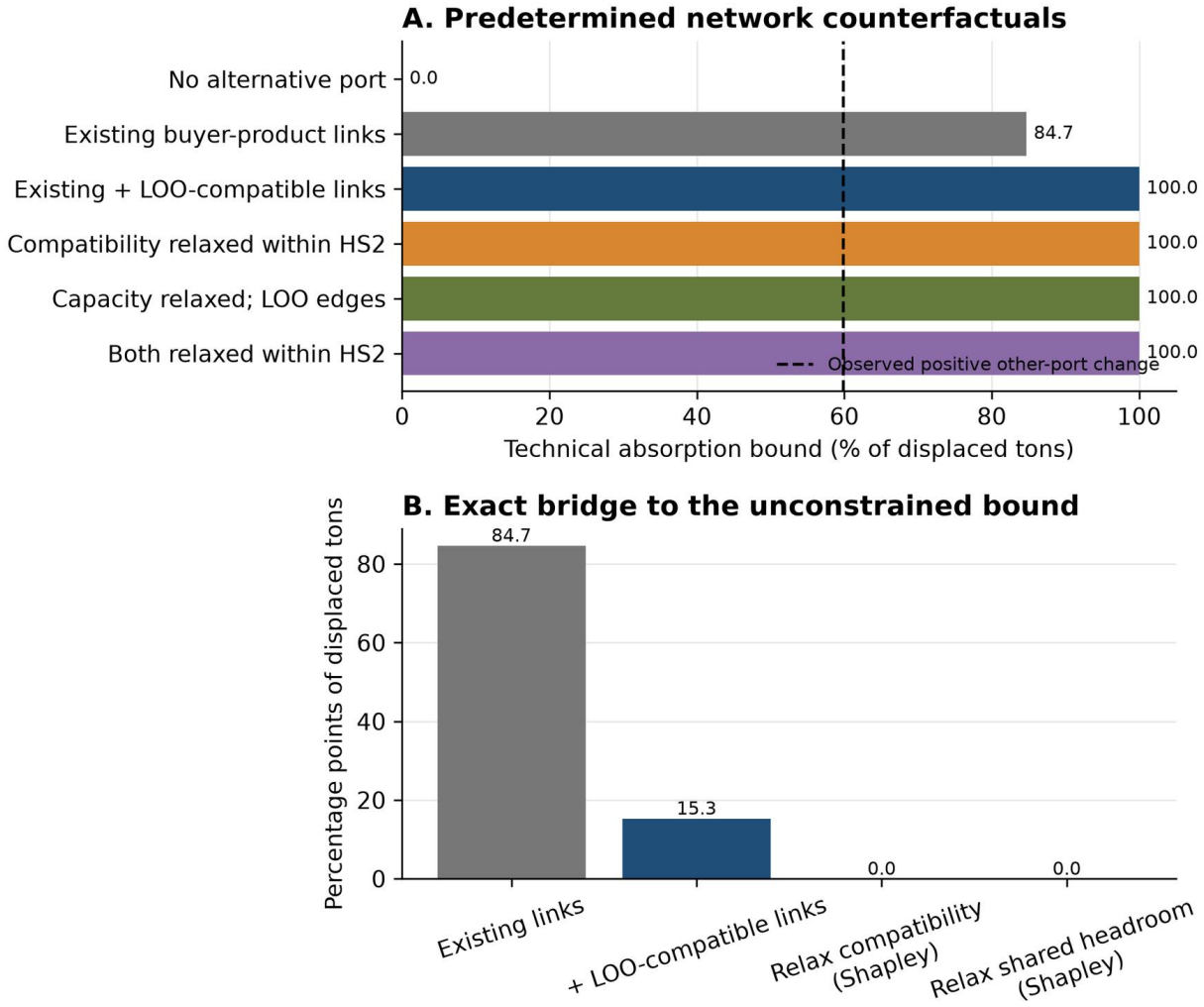
Notes: schedules in force on 26 March 2024. Baltimore converts metric tonnes to U.S. net tons at 1 MT = 1.10231131 net tons. NYNJ (hatched) is conditional on public-facility/lease applicability. The bars exclude dockage, stevedoring, handling, storage and negotiated charges; they are posted benchmarks, not realized expenditure or full logistics cost.

Figure A11. Predetermined LOO compatibility: untouched 2023 validation



Notes: parameters are estimated on 2022 allocations using 2019-2021 features, then frozen. The strong benchmark includes historical own links, own port shares, and destination-LOO HS2 throughput envelopes. The full model adds destination-LOO HS6 RCA and two-year compatibility. The interval is a 1,999-draw destination-block bootstrap.

Figure A12. Baltimore closure: compatibility and fixed throughput headroom



Notes: displaced demand is Baltimore vessel-export tonnage with a positive recorded shipping weight in April-May 2023; missing or nonpositive weights are excluded, never recoded to zero. Shared headroom is the p95 two-month 2019-2022 all-product export-throughput envelope minus April-May 2023 load, imposed both within HS2 and district-wide. Destination-LOO throughput support is used in the held-out link-validation stage; the system counterfactual necessarily imposes common shared headroom across buyers. Bars are continuous maximum-flow bounds, not equilibrium or welfare estimates. Panel B uses a two-by-two Shapley allocation so compatibility and headroom contributions sum exactly despite interaction. The dashed line is the positive 2024 change at other U.S. ports for the same destination-product relationships.