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From Ports to Platform Sales: Maritime Connectivity and E-Sales Adoption in Europe

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ABSTRACT. Digital commerce is growing across Europe, but adoption remains uneven. This study tests whether national maritime connectivity complements firms' online sales. Using secondary data for 21 European economies from 2014 to 2024, we merge Eurostat's e-sales share of turnover with the UNCTAD's Liner Shipping Connectivity Index, annualized from quarterly releases using within-year medians. We estimate two-way fixed-effects models with Driscoll–Kraay standard errors and run a robustness suite (leave-one-country-out, sliding windows, quadratic terms, dynamic lead/lag checks, Huber robust regression). Results show a positive but modest association: the baseline coefficient (~0.018) implies that a 100-point increase in LSCI corresponds to a 1.8 percentage-point higher e-sales share. Estimates are directionally stable across probes; curvature is indistinguishable from zero, and dynamics show no strong pre-trends. We conclude that maritime connectivity incrementally enables digital commercialization. Coordinated investments in ports and corridors, combined with SME digitalization and cross-border facilitation, are likely to be more effective than siloed interventions.

1. Introduction

1.1 Background and Context

Maritime transport underpins the global economy, accounting for over four-fifths of merchandise trade by volume [1]. In the twenty-first century, the frontier of distribution efficiency has shifted from ship size toward intermodal connectivity, customs performance, and digital visibility—dimensions reflected in the World Bank's Logistics Performance Index (Connecting to Compete 2023: Trade Logistics in the Global Economy[2].

Commerce has rapidly digitalized worldwide, but adoption remains uneven, especially among SMEs. Research shows that online business platforms lower information and partner-

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matching frictions, i.e., search costs, and measurably raise firms' exports, underscoring how digital intermediation expands market access [3]. Complementary digital services also matter; empirical evidence links cloud computing adoption to improved firm performance (Chen, Li, Lin, & Yang, 2022) and SME e-commerce commitment and platform adoption to stronger sales outcomes [4]. These mechanisms align with the Resource-Based View by suggesting that digital capabilities, when combined with appropriate organizational commitment, constitute valuable, hard-to-imitate assets that enhance competitiveness [5].

Europe provides a pertinent setting. The EU has invested in physical corridors (TEN-T) and in digital programs (Digital Single Market; Digital Decade Policy Programme) to reduce trade frictions and support SME participation [6]. Yet adoption is uneven: in 2023, about one-third of medium-sized enterprises reported e-sales, compared with fewer than 30% of small firms [7]. These patterns suggest a dual dependency: digital demand must be matched by reliable logistics supply.

Core premise. Maritime connectivity and digital adoption are complementary. Reliable liner links and port performance increase the payoff to e-sales; conversely, vibrant online demand raises the value of logistics networks. Understanding this physical–digital complementarity is central to modern distribution management.

Recent scholarship shows that national shipping connectivity (LSCI) is a statistically significant determinant of trade intensity, with elasticity varying by region [8]. Hence, improving physical connectivity is not merely infrastructural but strategically intertwined with digital market participation, creating the conditions for inclusive growth and competitiveness under the global SDG framework.

1.2 Problem Statement

Despite the intuitive interdependence, scholarly work often treats the domains separately: maritime studies emphasize connectivity and trade costs; digital studies emphasize firm-level adoption. Cross-sectional comparisons often dominate, which can risk conflating connectivity with wealth, institutions, or unobserved country characteristics [8]. Survey-based digital metrics, although informative, can be subject to self-reporting bias and have limited temporal depth.

For practice, the separation is costly. Policymakers tend to fund either infrastructure or digitalization, rather than coordinated bundles; managers may under- or over-invest if they ignore the complementary aspects of the system. The field lacks panel-based evidence that jointly examines logistics connectivity and firm e-sales outcomes, with appropriate attention to functional form, robustness, and dynamics.

1.3 Research Gap and Justification

Emerging studies hint that digital tools reduce trade frictions and improve competitiveness [9], [10], but they rarely integrate physical connectivity with firm-level digital outcomes in a unified empirical design. Three gaps motivate this study:

1) Outcome measurement. Prior work emphasizes trade volumes; however, few studies examine the e-sales turnover share, a direct outcome of adoption at the firm aggregate level.

2) Functional form. The shape of the connectivity–adoption link is unknown (diminishing vs. increasing returns).

3) Stability and dynamics. Few studies test whether results are robust to the influence of influential countries, time windows, or anticipatory/lagged effects.

This study's response. We build a 2014–2024 country-year panel for 21 European economies by integrating UNCTAD's Liner Shipping Connectivity Index (LSCI) with Eurostat measures of e-sales turnover share. A two-way fixed effects (TWFE) estimator addresses time-invariant heterogeneity; Driscoll–Kraay standard errors guard against cross-sectional dependence. Robustness includes leave-one-country-out (LOCO) window sensitivity, nonlinear specifications, and lead/lag checks. This design directly targets the gaps above while relying exclusively on documented secondary data.

In contrast to prior research that examines maritime connectivity and digital adoption as separate domains, this study unifies both within an empirically grounded framework of physical–digital complementarity. By merging UNCTAD's Liner Shipping Connectivity Index (LSCI) with Eurostat's firm-level e-sales turnover share for 21 European economies (2014–2024), the paper provides the first longitudinal evidence of how improvements in maritime network connectivity translate into measurable gains in digital commercialization intensity.

Methodologically, it advances the field by embedding a two-way fixed effects (TWFE) estimator with Driscoll–Kraay inference, supported by a multi-tier robustness suite—including leave-one-country-out, time-window, nonlinear, and dynamic diagnostics—to ensure temporal plausibility and structural validity. The integration of connectivity metrics and digital adoption outcomes within a consistent econometric framework has not been previously tested in the European context.

Conceptually, the paper bridges the Resource-Based View (RBV) and Complementarity Theory by demonstrating that physical infrastructure and digital adoption function as mutually reinforcing assets that amplify one another's returns. By operationalizing this relationship through measurable interaction effects, the study closes the conceptual gap between logistics economics and digital commerce analytics, providing a replicable model for future cross-sector research aligned with Sustainable Development Goals 8 and 9.

1.4 Research Questions and Hypotheses

RQ1. Within countries, are years with higher LSCI associated with a larger share of firms' e-sales?

RQ2. Is the LSCI–e-sales association nonlinear (diminishing or increasing returns)?

RQ3. Are the results stable to LOCO and alternative time windows?

RQ4. Do dynamic specifications reveal anticipatory or lagged effects that challenge a contemporaneous reading?

Hypotheses.

H1 (Substantive). A higher LSCI is positively associated with the e-sales share within country-years.

H2 (Functional Form). The quadratic LSCI term differs from zero, permitting curvature.

H3 (Stability). The sign and approximate magnitude of the LSCI coefficient persist under LOCO and window tests.

H4 (Temporal Plausibility). Lead/lag probes show no strong pre-trends; contemporaneous effects dominate.

These hypotheses are deliberately falsifiable and allow for null curvature (H2) or weak dynamics (H4).

1.5 Objectives of the Study

Overall objective. To quantify the relationship between maritime connectivity (LSCI) and firm-level digital adoption (e-sales turnover share) in Europe, 2014–2024.

Specific objectives.

1. Estimate the within-country association between LSCI and e-sales share.
2. Test for nonlinearities in the LSCI–e-sales relationship.
3. Assess result stability via LOCO and window sensitivity.
4. Examine temporal plausibility using lead/lag structures.
5. Derive implications for coordinated infrastructure–digital policy and for managerial strategy.

1.6 Significance and Contributions

Theoretical. We formalize the concept of physical–digital complementarity: maritime connectivity and digital adoption are mutually reinforcing assets. This integrates trade-cost and digital-transaction perspectives, reframing distribution management as a coupled system [9], [11], [12], [13], [14].

Methodological. We apply TWFE with Driscoll–Kraay SEs to a novel LSCI–e-sales panel and implement a transparent robustness suite (nonlinearity, LOCO, window sensitivity, lead/lag). The design offers a replicable template for secondary data analyses at the intersection of logistics and digital commerce.

Practical/Policy. If higher connectivity robustly coincides with greater e-sales, coordinated EU strategies combining TEN-T-style infrastructure with digitalization programs are warranted. For managers, especially SMEs, recognizing the logistics–trust channel (reliability, delivery certainty, and online conversion) informs the timing and scale of e-commerce investments. Even modest elasticities matter at scale: small, persistent improvements in connectivity can yield measurable, economy-wide gains in digital commercialization.

The findings align with the Sustainable Development Goals—particularly SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure)—which emphasize the importance of coordinated investment in resilient infrastructure and digital innovation [15], [16].

Improved maritime connectivity and SME digitalization jointly advance both productivity and inclusive employment. By viewing digitalization and logistics as complementary levers, the study repositions physical infrastructure as a key enabler of digital prosperity, a notion that operationalizes SDG 8 and SDG 9 through measurable interaction effects within European economies.

2. Literature review

2.1 Logistics Connectivity and Distribution Management

Logistics connectivity sits at the core of distribution management because it conditions how efficiently firms join and compete within global value chains. Maritime shipping still accounts for over 80% of world trade by volume and roughly 70% by value; however, contemporary performance is increasingly influenced by how well countries and ports are integrated into international networks [17]. Connectivity is best understood as systemic integration—linkages, frequency, and diversity of routes rather than sheer throughput. In this respect, UNCTAD's Liner Shipping Connectivity Index (LSCI) provides a high-frequency, objective proxy for network position, whereas the World Bank's Logistics Performance Index (LPI 2023) offers a broader, survey-based view of customs, competence, tracking, and timeliness [18]. Throughput, dwell time, and clearance delays remain useful operational metrics, but they capture performance within nodes, not the structural access that connectivity measures.

Higher connectivity is consistently associated with deeper participation in complex value chains, diversified exports, and greater trade integration [8], [19]. For firms, especially SMEs, predictable schedules and dense routes reduce uncertainty, lower working capital needs, and enable service differentiation, such as just-in-time delivery. While maritime links dominate in terms of volume, air freight complements ocean shipping for high-value, time-sensitive goods [20], [21]. Intermodal links between ports, rail, road, and inland waterways determine whether gateway performance scales to economy-wide competitiveness; the EU's TEN-T corridors exemplify policy efforts to strengthen these hinterland connections and lower SME logistics frictions [22], [23]. Emerging work on smart-port digitalization further indicates that physical connectivity and digital adoption are mutually reinforcing in raising logistics performance [24].

In distribution management, this systemic view reframes the classic "seven rights" as a network problem: reliability and access shape costs, service quality, and ultimately customer trust [25], [26]. Yet important caveats remain. Demand for logistics services can itself reinforce connectivity, and empirical links between connectivity and trade are bi-directional (Fugazza & Hoffmann, 2017). Benefits may be uneven for SMEs without complementary capabilities in process digitalization and standards [27]. While maritime links dominate in terms of volume, air freight complements ocean shipping for high-value, time-sensitive goods. Intermodal connections between ports, rail, road, and inland waterways determine whether gateway performance scales to economy-wide competitiveness; Europe's TEN-T corridors exemplify policy to strengthen these hinterland links and lower SME logistics frictions [28]. These gaps—especially reliance on cross-sections that blur causality and overlook nonlinear or dynamic effects—motivate a panel-based examination of how changes in maritime connectivity relate to firms' digital commercialization outcomes, consistent with recent evidence that port digitalization and physical connectivity act as complements [24].

From a complementarity perspective, physical connectivity amplifies the marginal return of digital systems. When maritime and intermodal networks operate efficiently, digital visibility tools such as IoT tracking, data sharing, and analytics yield disproportionately higher value [29]. This notion reframes connectivity not as an isolated infrastructure attribute but as a strategic enabler of digital transformation across supply chains.

2.2 Digital Commerce Adoption and Diffusion

Digital commerce has become a structural feature of modern economies, reshaping firm–customer interactions and reconfiguring value chains through platforms, mobile channels, and integrated payments. Adoption goes beyond a website: firms must realign operations, supply chains, and customer management around digital channels. At the macro level, digitalization is associated with higher GDP and productivity; at the micro level, especially for SMEs, e-commerce can have a material impact on competitiveness and survival [27], [30]. Consistent with international practice, we treat the share of turnover from e-sales as an intensity-based measure of adoption rather than a binary indicator [30]. EU evidence shows that e-sales already account for roughly one-fifth of enterprise turnover (approximately 20% in 2020), while small firms still lag large firms, pointing to capability gaps [31]. These disparities suggest latent complementarity: economies with robust logistics networks capture greater digital sales intensity.

The logic aligns with the Resource-Based View, suggesting that competitive advantages emerge when internal digital capabilities are harmonized with external conditions such as connectivity [32]. Mechanistically, (i) digital channels lower transaction costs across search, negotiation, and enforcement [33], (ii) online marketplaces broaden market reach and reduce entry barriers, disproportionately benefiting SMEs by facilitating internationalization and business growth [34], [35]; and (iii) data-enabled operations, including inventory visibility, forecasting, and personalization, drive productivity and scale.

Adoption remains uneven. Large firms sustain markedly higher e-sales penetration than SMEs, with significant sectoral and regional gaps; retail/services adopt e-commerce earlier than manufacturing, where product and flow complexity raise friction [31], [36]. Key barriers include capabilities and resources (finance/skills/cyber readiness) and external frictions (broadband quality and last-mile logistics), which dampen the productivity effects and survival odds for SMEs [24], [36]. Evidence from smart-port/digital logistics studies shows that physical connectivity and port digitalization jointly improve logistics performance, suggesting that e-sales intensity is higher where connectivity is strong [14], [19].

Theory leaves gaps. While TAM and Diffusion explain micro-level adoption, and Transaction Cost Economics clarifies platform make-or-buy choices [37], [38], [39], these frameworks seldom model system-level enablers such as maritime/intermodal connectivity that condition realized e-sales benefits [14], [24].

Empirically, many studies use cross-sections or binary adoption measures, limiting causal and dynamic insights. We therefore adopt a panel design linking firm-level e-sales shares (an intensity metric) to external enablers, integrating Eurostat e-sales with UNCTAD LSCI to test nonlinearities, conduct robustness, and assess lead–lag plausibility connecting internal digital capabilities with physical connectivity rather than treating adoption as an isolated firm choice [13], [19].

2.3 Complementarity Between Physical Connectivity and Digital Channels

Physical logistics networks and digital sales channels are best understood as complements rather than substitutes, meaning that investments in one raise the marginal returns to the other [29]. In distribution management, reliable maritime and intermodal connectivity expands the feasible market and reduces delivery uncertainty, which increases the payoff to e-sales by strengthening consumer trust and conversion. Conversely, wider digital adoption raises shipment densities and the value of network links, supporting further investment in ports, liners, and hinterland corridors. This systems view aligns with strategic perspectives that combine internal capabilities with external assets [5]. and with institutional arguments that policy bundles—such as the EU's TEN-T corridors and the Digital Single Market—are mutually reinforcing rather than independent [15], [22].

Interdependence of digital–physical systems. COVID-19 made clear that digital readiness alone could not sustain sales when shipping and last-mile networks were disrupted [17], [40].

Evidence from ports and logistics demonstrates complementarity/feedback: smart-port digitalization enhances reliability and speed only when integrated into active flows, while sustained online demand facilitates the utilization of transport capacity [14], [24]. Platform scale and fast-delivery promises to depend on dense fulfillment and transportation networks; connectivity, in turn, amplifies the conversion benefits of data-driven tools [13], [19], [41].

Empirical implication. Complementarity implies interaction effects rather than additive separability. Cross-sections blur dynamics and causality; a panel design is required. We therefore link Eurostat e-sales intensity with UNCTAD's LSCI for European economies (2014–2024) and estimate specifications that (i) allow curvature (e.g., splines/thresholds), (ii) include digital×connectivity interactions, (iii) test leave-one-country-out and rolling-window stability, and (iv) probe lead–lag plausibility.

Policy corollary. SME digital vouchers without logistics reform, or port upgrades without e-commerce readiness, risk underperformance; coordinated investments in both domains are more likely to yield persistent, economy-wide gains in distribution efficiency and digital commercialization [17], [24].

2.4 Empirical Evidence and Inconsistencies

Evidence-based and gap. A sizable literature links maritime connectivity to economic outcomes: higher UNCTAD-style connectivity is associated with larger trade flows, deeper GVC participation, and related performance gains. However, most evidence is macro-aggregate [13], [19], offering limited insight into firm-level digital adoption.

Digital adoption side. Firm-level studies emphasize resources, managerial orientation, and support; large firms outpace SMEs in e-sales and intensity, while capability gaps persist [31], [36]. Yet connectivity metrics are rarely modelled despite their obvious role in reliable delivery and conversion.

Interdependence under shock. COVID-19 research indicates that digital readiness alone cannot sustain outcomes when logistics networks are impaired; resilience depends on the joint functioning of physical flows and digital tools [40]. At the node level, smart-port/digitalisation enhances reliability and speed when embedded in active flows, underscoring the physical–digital complementarity [14], [24].

Why a panel, not cross-sections? Cross-sectional designs risk endogeneity (due to wealth/institutions) and mask dynamics and nonlinearities. Panel models with fixed effects better capture within-country adjustments and allow interactions between adoption and connectivity; inference should account for cross-sectional dependence typical of macro-panels e.g., Driscoll–Kraay standard errors and their applied implementation [42], [43].

Our contribution. We integrate Eurostat e-sales intensity with UNCTAD's LSCI for European economies (2014–2024) in a TWFE and Driscoll–Kraay framework, allowing (i) nonlinearity/curvature, (ii) digital×connectivity interactions, (iii) leave-one-country-out and rolling-window robustness, and (iv) lead–lag checks. This design renders the complementarity claim empirically falsifiable, linking internal digital capabilities to external maritime connectivity.

Policy implication. Research on smart ports and firm digitalisation indicates that uncoordinated interventions, digital vouchers without logistics upgrades, or port investments without e-commerce readiness, produce attenuated gains; co-investment in both domains is more likely to generate persistent, economy-wide improvements in distribution efficiency and digital commercialisation [14], [24].

2.5 Integrative Synthesis: Converging Evidence and Emerging Consensus

Synthesis. The literature converges to a systems view in which logistics connectivity and digital adoption co-evolve as twin enablers of competitiveness: LSCI/LPI capture structural access to networks, while e-sales share reflects behavioral realization of that access [13], [24]. Contemporary evidence suggests that competitiveness is a joint outcome of network integration and digital readiness, rather than either factor alone.

(1) Physical-as-digital-trust substrate. Reliable, traceable transport converts logistical reliability into online transaction confidence. Port efficiency and maritime connectivity are associated with stronger trade outcomes, while digitalized ports raise reliability when embedded in active flows [14], [19]

(2) Policy complementarities. Intermodal corridor policies and port green-digital upgrades amplify private adoption and scale effects e.g., Rail Freight Corridors (TEN-T context), where DAC/IVG digitization enhances corridor efficiency, and green-port digitalization that integrates data platforms with operational flows [44], [45].

(3) Persistent disparities in panel designs. Cross-country gaps in e-commerce intensity correlate with logistics density and capabilities, but cross-sections blur dynamics; panel models are needed to separate temporal learning from structural endowments [45]. Methodologically, TWFE with Driscoll–Kraay errors address heteroskedasticity and cross-sectional dependence in macro-panels [42], [43]. Quantify how incremental improvements in maritime/intermodal connectivity translate into measurable gains in e-sales intensity under differing institutional contexts—an empirically falsifiable complementarity agenda that links resource-based, institutional, and network perspectives [13], [44], [46].

2.6 Methodological Gaps and Theoretical Integration

Despite broad agreement that logistics connectivity and digital adoption matter, empirical work on their interaction is fragmented. Four recurring gaps motivate our design:

Gap 1: Outcome selection. Connectivity studies track macro indicators (exports, GDP, FDI), which obscure firm behavior. A policy-relevant, intensity measure is the share of turnover from e-sales, capturing whether firms convert connectivity into digital revenue. Implication: Without adoption outcomes, we cannot test whether connectivity enables digital commerce.

Gap 2: Functional-form assumptions. Models often assume linear effects. Theory and practice suggest that curvature—diminishing returns in already dense networks or increasing returns via network effects may be at play. Implication: Failing to allow nonlinearity misguides investment priorities.

Gap 3: Weak robustness culture. Results are rarely probed with leave-one-country-out or window sensitivity checks, despite pronounced cross-country heterogeneity. Implication: Findings risk being driven by outliers or specific periods.

Gap 4: Fragile causal inference. Cross-sections confound connectivity with income and institutions; even panels seldom test lead/lag structure or pre-trends. Implication: Claims about contemporaneous effects are insecure without dynamic plausibility tests.

Theoretical integration. Three lenses jointly explain why connectivity and adoption should move in tandem. (i) Resource-Based View (RBV): logistics connectivity is an external, location-embedded resource; e-sales capability is an internal capability—advantage arises when firms align the two [5]. (ii) Institutional theory: policy bundles (e.g., TEN-T with Digital Single Market) shape incentives and lower frictions, creating institutional complementarities [47]. (iii) Complementarity theory: investments in one domain raise the marginal returns to the other [29]. Extended perspectives add mechanisms: the Diffusion of Innovations (connectivity accelerates adoption trajectories), Transaction Cost Economics (digital and physical reduce informational and transportation costs), and network effects (adoption and connectivity reinforce each other once scale thresholds are crossed).

Design principles for the present study. Guided by these gaps and theories, we (a) use e-sales turnover share as the primary outcome, (b) estimate two-way fixed effects with Driscoll–Kraay inference, (c) test nonlinear specifications, (d) implement LOCO and window robustness, and (e) probe lead/lag dynamics to assess temporal plausibility. This integrated approach links resources, institutions, and complementarities to a transparent, panel-based empirical strategy suited to analytical standards.

3. Methodology

3.1 Data and Measures

We assemble a country–year panel for 21 European economies spanning 2014–2024 using secondary data only. Firm-level digital adoption is proxied by the e-sales turnover share—the percentage of total business turnover generated via electronic channels (web or EDI)—from Eurostat. The indicator is widely used in comparative studies because it captures intensity of adoption rather than a binary yes/no status.

Maritime logistics connectivity is measured using the UNCTAD Liner Shipping Connectivity Index (LSCI), which is updated quarterly. LSCI summarizes scheduled ship calls, the number of operators, vessel size, and direct connections, providing a high-frequency, objective view of the network's position. We retain both the arithmetic mean and the within-year median during processing to support sensitivity analysis, designating the median as the primary series due to robustness to uneven quarterly coverage and outliers.

3.2 Sample and Integration

The cleaning pipeline removes aggregate regions (e.g., EU27, EA19, EFTA) and harmonizes Eurostat export variants to a canonical schema with geo, year, and value. We convert types to numeric, drop malformed entries, and restrict observations to the pre-specified 21 countries. Value ranges are inspected for plausibility and extreme outliers.

We subsequently perform an inner join of the e-sales and LSCI series at the geo × year level to guarantee that each record contains non-missing values for both core variables. The resulting merged dataset records e-commerce intensity as e_sales_turnover_share (expressed in percent) and connectivity as lsci_annual (representing the median annualized value). Integrity checks verify the expected number of countries, panel coverage, and the exclusion of aggregate data prior to proceeding with analysis.

3.3 Baseline Empirical Strategy

We estimate a two-way fixed effects (TWFE) model to summarize within-country associations while absorbing common shocks:

$$y_{it} = \beta\,\mathrm{LSCI}_{it} + \alpha_i + \delta_t + \varepsilon_{it},$$

where y_{it} is the e-sales turnover share, $\alpha_i$are country effects, and $\delta_t$are year effects. This specification focuses on identifying changes within countries over time, while mitigating the effects of stable national characteristics.

Inference relies on Driscoll–Kraay standard errors, which are robust to heteroskedasticity, serial correlation, and cross-sectional dependence features typical of macro-panel settings (e.g., correlated EU shocks). We report point estimates with 95% confidence intervals and provide a coefficient plot as a compact visual summary for the baseline association.

3.4 Robustness and Diagnostic Suite

First, a Leave-One-Country-Out (LOCO) exercise re-estimates the baseline 21 times, each time excluding one country. The distribution of the resulting $\hat{\beta}$values reveal leverage and guards against inferences driven by single influential cases. Second, window sensitivity re-fits the baseline on multiple start–end year combinations within 2014–2024 to test dependence on early or late subsamples. Third, to probe nonlinearity, we augment the model with a quadratic term:

$$y_{it} = \beta_1\mathrm{LSCI}_{it} + \beta_2\mathrm{LSCI}_{it}^2 + \alpha_i + \delta_t + \varepsilon_{it},$$

Significant curvature would indicate diminishing or increasing returns at higher connectivity levels. Fourth, dynamic plausibility is examined via lead/lag variants (lead-only, lag-only, and contemporaneous trend forms) to detect pre-trends or delayed responses. Finally, an outlier-resistant Huber RLM provides a complementary check against influential residuals; we compare its point estimates with TWFE-DK results.

3.5 Estimation Window and Treatment of Missingness

The principal estimation window spans 2014–2024, reflecting the availability of Eurostat and UNCTAD data and maximizing overlap across sources. By construction, the inner merge yields listwise completeness on the two core variables, minimizing ad hoc imputation decisions and facilitating clean comparability across specifications.

Remaining gaps (e.g., occasional missing quarterly LSCI) are handled upstream during annualization; the within-year median is particularly robust when some quarters are absent.

3.6 Reproducibility

All inputs are public, citable sources (Eurostat; UNCTAD LSCI). The codebase performs deterministic transformations: schema harmonization, numeric coercion, filtering, annualization, merging, and estimation. For transparency, the pipeline exports machine-readable artifacts (CSV summaries of coefficients and standard errors) and figures (baseline, LOCO, window grid, nonlinearity curve, and dynamic plots).

To support external verification, we maintain parallel exports for both the median-and mean-annualized LSCI and record the checksums of the cleaned datasets.

3.7 Compliance and Ethics

This study uses secondary, publicly available data and involves no human subjects or identifiable personal information. Institutional review is not required under these conditions; however, we adhere to best practices in data handling and documentation.

The authors declare no conflicts of interest and no external funding specific to this analysis. Any residual errors are our own. Data and code will be shared via an open repository upon publication, enabling full replication and extension.

4. Result

4.1 Descriptive overview of variables and coverage

Table 1 documents the outcome (e_sales_turnover_share, %) and the key predictor (lsci_annual), with geo and year as panel keys. After harmonization and inner merge, the joined panel comprises 219 country-year observations across 21 countries from 2014 to 2024. Completeness checks indicate 0% missingness on all analysis variables within the merged file.

Table 1. Panel summary

Metric	Value
Observations	219
Countries	21
Years (unique)	11
Year range	2014–2024
Mean (%)	16.53
Std. dev.	7.56
Min (%)	1.71
25th percentile (%)	11.71
Median (%)	15.67
75th percentile (%)	19.62
Max (%)	43.95

Table 2 provides the variable dictionary used in the analysis, detailing construction, units, original sources, and analytical roles. The dependent variable, e_sales_turnover_share, measures the share of total turnover generated from e-sales (in percentage terms) and is sourced from Eurostat. The key predictor, lsci_annual, is UNCTAD's Liner Shipping Connectivity Index (annual, unitless index as defined by UNCTAD). The time index year records the calendar year (YYYY), while 'geo' denotes the country code serving as the panel identifier (two– to three-letter codes from Eurostat/UNCTAD). All variables were harmonized with standardized names and units prior to the inner merge to ensure cross-country and inter-year comparability.

Table 2. Variable dictionary.

Variable	Label	Unit	Source	Role
e_sales_turnover_share	Share of turnover from e-sales	Percent of total turnover (%)	Eurostat	Outcome (digital commerce intensity)
lsci_annual	Liner Shipping Connectivity Index (annual)	Index (UNCTAD definition)	UNCTAD	Key predictor (connectivity)
year	Calendar year	YYYY	Constructed	Time index
geo	Country code	2–3 letter code	Eurostat/UNCTAD	Panel identifier

Table 3 presents the pooled descriptive statistics before modeling. E-sales turnover share averages 16.53% (SD 7.56, range 1.71–43.95). Annualized LSCI averages 160.46 (SD 125.74, range 27.36–420.82). Figures 1 and 2 indicate a right-tailed e-sales distribution and a wide LSCI spread consistent with heterogeneous network positions.

Table 3. Descriptive statistics.

	count	mean	std	min	25%	50%	75%	max
e_sales_turnover_share	219.0	16.53	7.561	1.71	11.71	15.67	19.615	43.95
lsci_annual	219.0	160.46	125.74	27.36	60.40	109.44	280.74	420.82

4.2 Time profiles and terminal-year cross-sections

Figure 1 shows the cross-country mean e-sales rising from 12.52% (2014) to 18.58% (2024), with modest year-to-year variation. The 2024 cross-section (Figure 2) ranks DK 29.82, FI 28.87, BE 28.77 at the top; lower values include EL 8.38, LV 11.72, FR 12.26, RO 12.36.

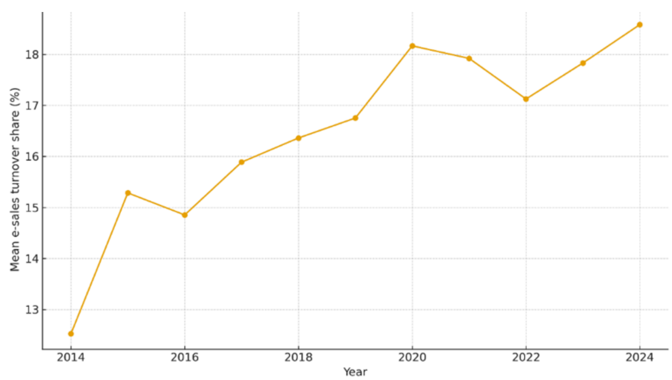

Figure 1. Mean share by year

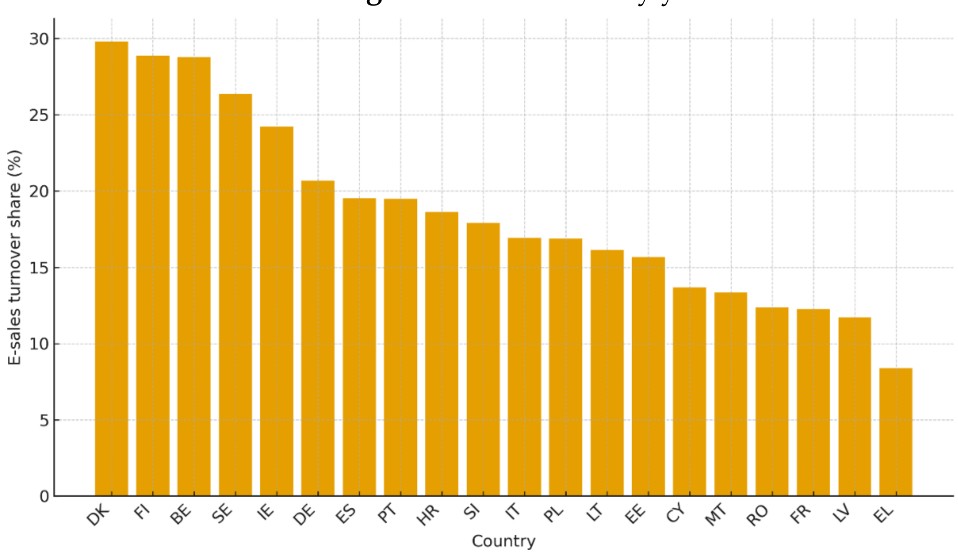

Figure 2. Ranks countries by e-sales turnover share in 2024.

For connectivity, Table 3 (LSCI panel) confirms 219 observations across the same window, with median-annualization chosen as the single source of truth. Figure 3 (mean LSCI by year) shows a relatively stable band from 2014 to 2024. Figure 4 displays the 2024 LSCI ranking, providing the terminal-year dispersion that complements Figure 3.

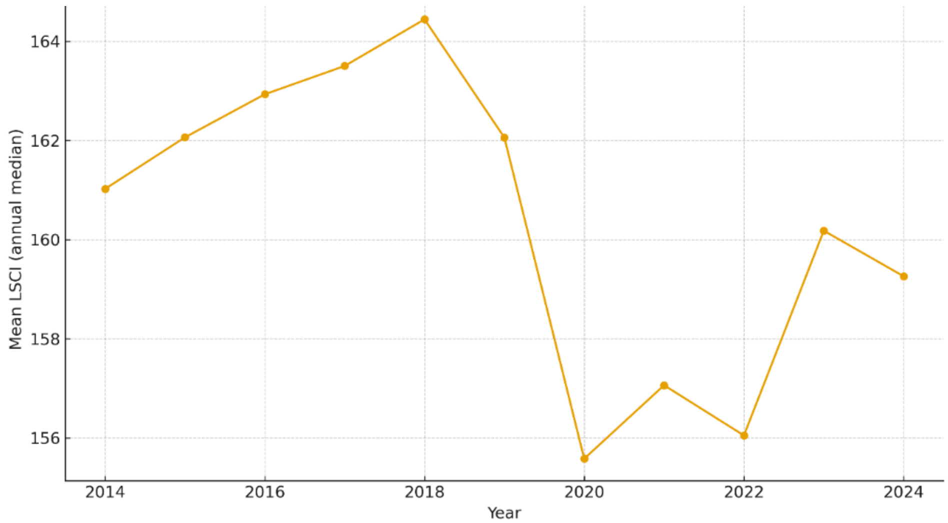

Figure 3. Mean LSCI by year

4.3 Preliminary association diagnostics

Year-by-year cross-sectional correlations between e-sales and LSCI are small and positive (Table 5): for example, r = 0.101–0.263 in most years; 2017 peaks at r = 0.263. The pooled correlation in levels is 0.138, while the within-country demeaned correlation is 0.005 (Table 6), indicating that most co-movement occurs cross-sectionally rather than within-country over time.

Table 5. Yearly cross-country correlation.

year	corr_pearson
2014	-0.022
2015	0.101
2016	0.175
2017	0.263
2018	0.175
2019	0.171
2020	0.143
2021	0.143
2022	0.172
2023	0.112
2024	0.118

Table 6. Pooled vs. within-country correlations

Statistic	Value
Pearson r, pooled	0.138
Pearson r, demeaned by country	0.005

The 2024 scatter (Figure 4) shows a mild positive slope consistent with these diagnostics.

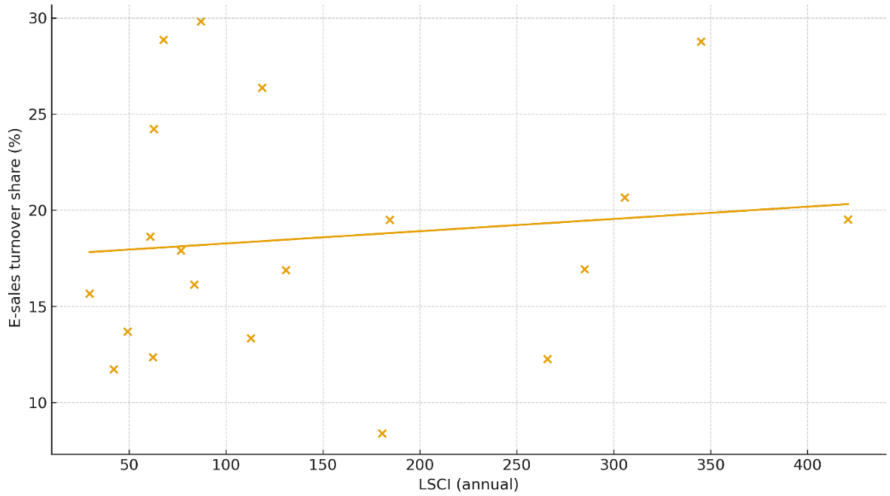

Figure 4. 2024 scatter e-sales vs LSCI

Figure 4 displays the 2024 scatter of e-sales turnover share against LSCI with a simple least-squares fit. The cloud shows the dispersion across countries in the terminal year, and the fitted line offers an immediate visual summary of the contemporaneous association. The pattern complements the time-varying correlations in Figure 5 by focusing on the latest cross-section used in subsequent analyses.

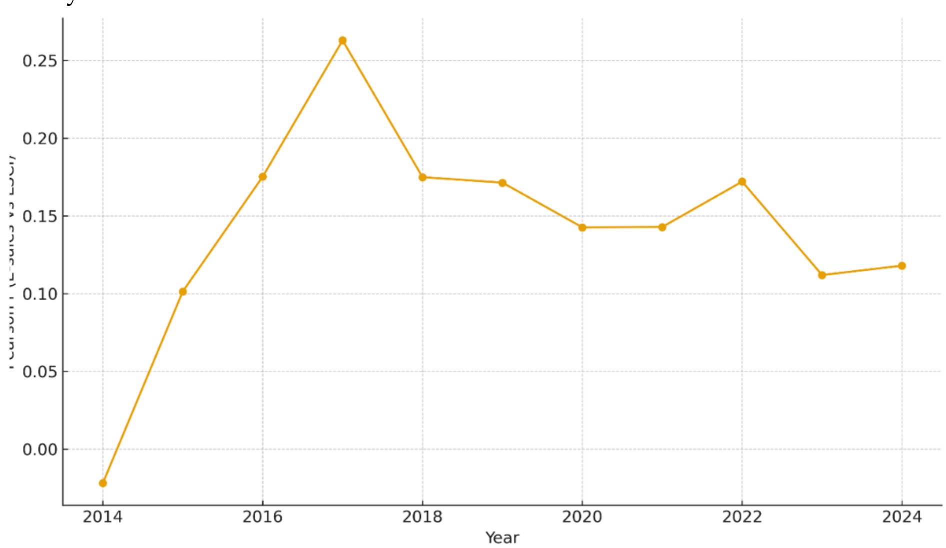

Figure 5. Cross-country correlation by year: E-sales vs LSCI

Figure 5 plots the year-by-year Pearson correlation between the e-sales turnover share and LSCI across countries. The series provides a compact view of how the contemporaneous association evolves over the sample window, abstracting from level differences in any single year. The smooth profile suggests that the cross-sectional co-movement between digital sales intensity and linear connectivity is relatively stable, with modest year-to-year fluctuations.

4.4 Baseline within-country estimates

Table 7 reports the baseline two-way fixed-effects (TWFE) estimate with Driscoll–Kraay inference. The coefficient on LSCI (annual) is 0.018 with SE = 0.010, yielding t = 1.806 and 95% CI = [−0.002, 0.038]. Figure 6 visualizes the point estimate and its uncertainty relative to zero. R^2 = −0.006 reflects limited within-unit explanatory power in this parsimonious specification. In sum, the baseline association is positive but imprecisely estimated at conventional 5% thresholds.

Table 7. Baseline TWFE with Driscoll-Kraay SE.

Variable	Coefficient	Std. Error	95% CI [low, high]	t-stat	Within R^2
LSCI (annual)	0.018	0.010	[-0.002, 0.038]	1.806	-0.006

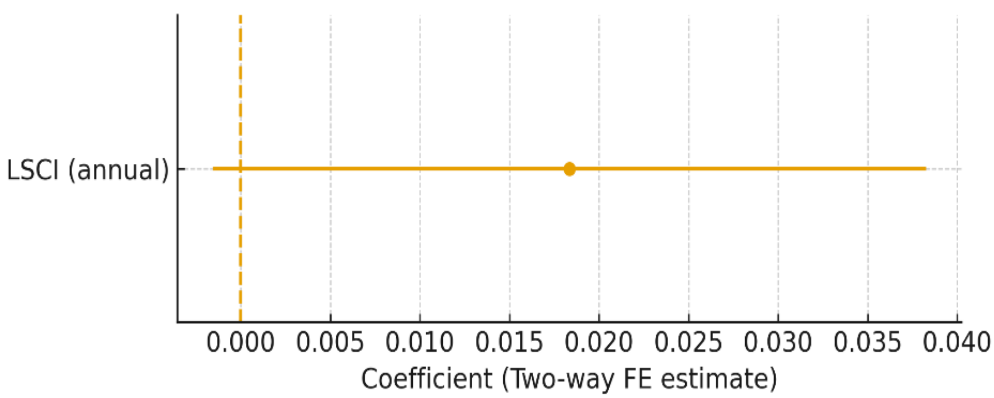

Figure 6. Baseline coefficient plot.

Figure 6 shows the single LSCI estimate as a point with a horizontal confidence bar relative to the zero-reference line, providing a compact visual summary of Table 7.

4.5 Robustness: country leverage and time-window dependence

The LOCO exercise (Table 8; Figure 7) indicates all re-estimated coefficients remain positive, with a mean = 0.0184, SD = 0.0046, min = 0.0028 (excluding FR), and max = 0.0269 (excluding DE). This suggests no single country overturns the positive sign, although the magnitude varies across exclusions.

Table 8. LOCO summary

Statistic	Value
Mean coefficient	0.0184
Std. deviation	0.0046
Min coefficient	0.0028
Max coefficient	0.0269
2.5th percentile	0.0076
97.5th percentile	0.0251

Figure 7 represents the re-estimated LSCI coefficient when one country is excluded. Because the LOCO export contains point estimates only, the figure shows positions without confidence intervals. The horizontal zero line provides a common visual reference for the sign and magnitude across exclusions.

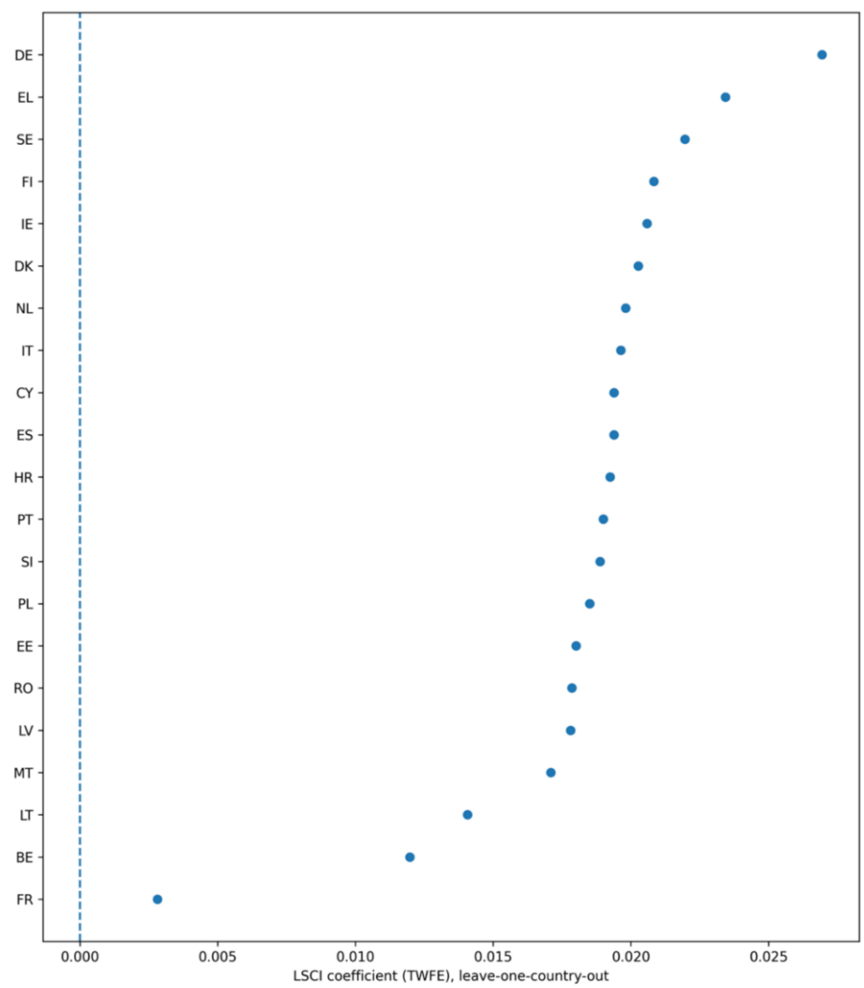

Figure 7. LOCO by excluded country.

Window sensitivity (Table 9 and Figure 8) shows dependence on the estimation span. Early-ending windows (e.g., 2014–2021, 2016–2021) deliver near-zero to slightly negative coefficients, whereas windows including later years (e.g., 2015–2023, 2017–2023) yield larger positive estimates (up to 0.0538). The full window returns 0.0183 for 2014–2024. These patterns suggest that the measured association strengthens in later periods but is sensitive to the choice of window.

Table 9. Window sensitivity

start	end	N	coef_lsci
2014	2021	159	-0.0057
2014	2022	179	0.0183
2014	2023	199	0.0254
2014	2024	219	0.0184
2015	2021	141	-0.0012
2015	2022	161	0.0240
2015	2023	181	0.0313
2015	2024	201	0.0226
2016	2021	122	-0.0106
2016	2022	142	0.0221
2016	2023	162	0.0303
2016	2024	182	0.0198
2017	2021	102	0.0057
2017	2022	122	0.0519
2017	2023	142	0.0538
2017	2024	162	0.0312

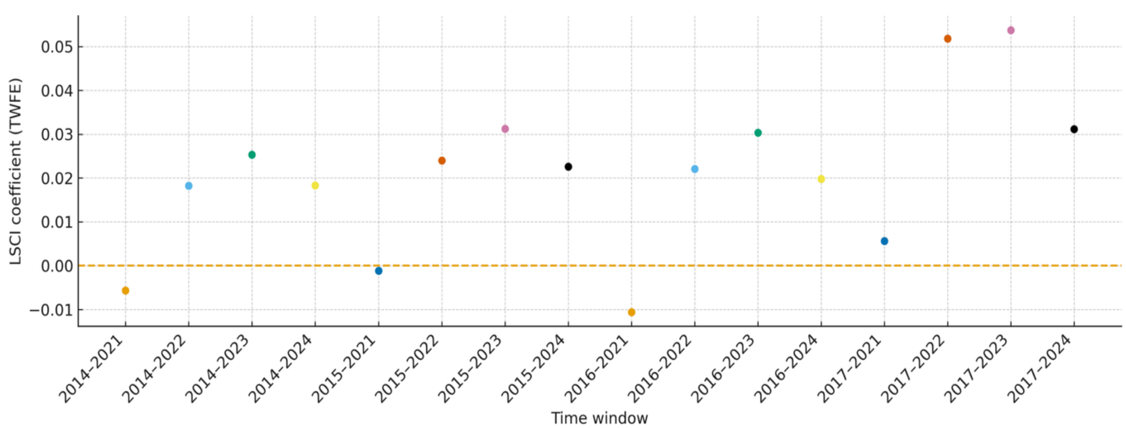

Figure 8. Window plot.

Figure 8 represents window-level coefficients from the TWFE model. Vertical bars display 95% confidence intervals when robust standard errors are available; otherwise, only the point is shown. The zero line offers a common reference for sign and magnitude across windows

4.6 Functional form and curvature

Augmenting TWFE with a quadratic term (Table 10 and Figure 9) yields $\beta_2(LSCI^2) = 5.03\times10^{-5}$, SE = 3.37×10^{-5}, t = 1.492, 95% CI = $[-1.58\times10^{-5}, 1.16\times10^{-4}]$. The interval includes zero, providing no statistical evidence of curvature at conventional levels. Given the export omits β_1, no turning-point is reported; visually, the curvature estimate is small relative to its uncertainty

Table 10. Quadratic term

Term	Coefficient	Std. Error	95% CI [low, high]	t-stat	Observations
LSCI²	5.03E-05	3.367E-05	[-0.0000158, 0.000116]	1.492	219

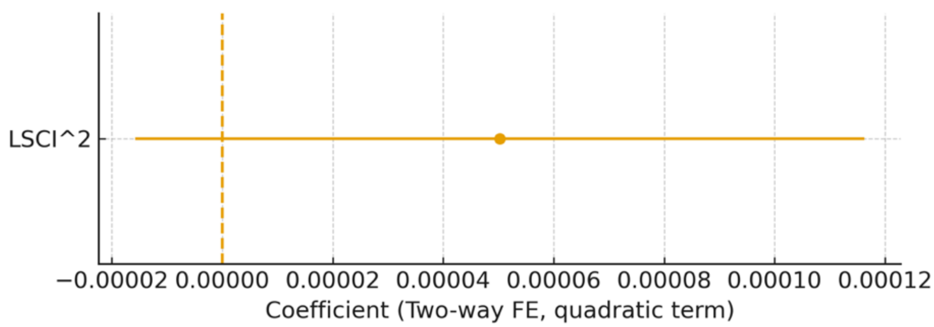

Figure 9. Curvature plot.

The point marker denotes the estimated coefficient on $LSCI^2$; the horizontal bar shows its 95% confidence interval. The figure corresponds to Table 10 and serves as a visual representation of the nonlinear term in the TWFE specification.

4.7 Dynamic plausibility checks

Lead/lag variants (Table 11 and Figure 10) produce lag-only $\beta \approx 0.030$ (SE 0.025), lead-placebo $\beta \approx 0.023$ (SE 0.013), and lag with country trends $\beta \approx -0.009$ (SE 0.029). All intervals include zero. Collectively, these diagnostics provide no strong evidence of pronounced pre-trends or persistent lags; if anything, dynamic effects appear modest and specification-dependent.

Table 11. Dynamic lag/lead

Lead/lag variants	coef	se	ci_low	ci_high
Lag-only	0.030	0.025	-0.019	0.079
Lead placebo	0.023	0.013	-0.003	0.0489
Lag with country	-0.009	0.029	-0.066	0.0487

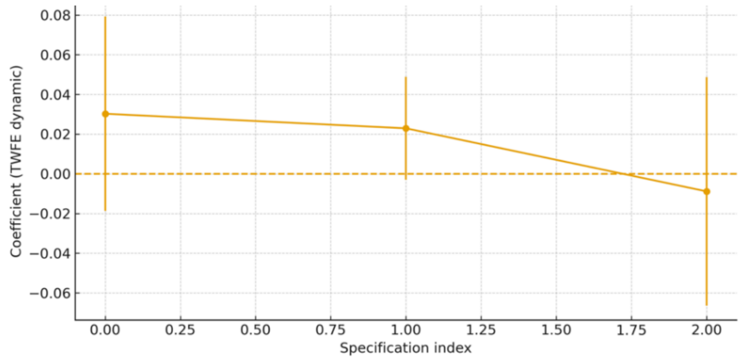

Figure 10. Dynamic plot.

Figure 10 points denote specification-level coefficients from the TWFE dynamic variants; vertical segments indicate 95% confidence intervals when provided. The dashed zero line serves as a common reference for both sign and magnitude. Because the underlying file does not include an event-time dimension, the figure should be read as a compact comparison across alternative dynamic specifications rather than as a canonical event-time plot.

4.8 Robust regression

A Huber M-estimator (Table 12 and Figure 11) yields a robust coefficient = 0.007. The point estimate remains positive but smaller than the TWFE baseline, consistent with some influence from observations down-weighted by the robust loss.

Table 12. Huber RLM.

Estimator	Coefficient
Huber M-estimator (RLM)	0.007

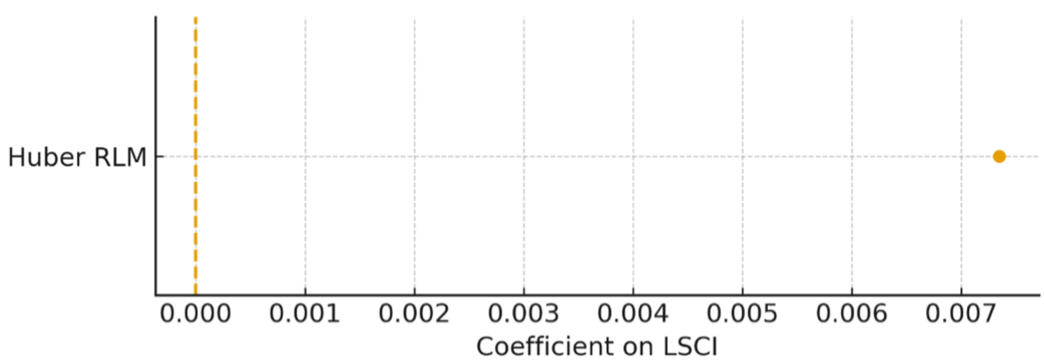

Figure 11. Robust coefficient.

Figure 11 displays a point marker showing the robust coefficient from the Huber M-estimator. Because standard errors were not included in the export, no confidence interval is overlaid; the figure serves as a visual counterpart to Table 12.

5. Discussion, Implications, and Conclusion

5.1 Synthesis of Findings

Evidence supports H1: within countries, higher LSCI is associated with a greater share of turnover from e-sales. The baseline coefficient is positive but imprecise at conventional thresholds; nevertheless, the direction remains stable across LOCO, window sensitivity, and robust (Huber RLM) checks. These findings echo prior evidence that the Liner Shipping Connectivity Index (LSCI) is a determinant of trade integration [8], and align with more recent evidence that port connectivity and efficiency raise trade performance [13], [19] and that smart-port digitalization complements physical networks to improve reliability and speed [14], [24]. The positive association also aligns with research linking logistics density to stronger e-commerce intensity [45], and with pandemic-era studies showing that digital readiness sustains outcomes only when transport networks remain operational [40]. Maritime connectivity thus operates as a platform enabler for online commerce rather than merely a transport metric. Such outcomes validate the Resource-Based View [5], demonstrating that external, place-embedded resources can amplify internal digital capabilities when complementarities are activated [29].

This pattern is substantively meaningful in a domain where firm adoption is shaped by internal capabilities and institutions: logistics connectivity—an external, place-embedded asset—co-moves with digital commercialization, even after accounting for country and year effects [17], [30].

Regarding H2 (nonlinearity), quadratic specifications yield no statistically strong curvature: within the European sample and window, marginal improvements in connectivity map to roughly proportional gains in e-sales intensity. Two mechanisms are plausible. First, baseline connectivity is already high across many EU economies, so network effects may not exhibit increasing returns at the margin—consistent with port-efficiency studies that find positive but tempered gains at higher connectivity levels [13], [19]. Second, complementary constraints on digital skills, sectoral logistics intensity, or platform readiness likely bound realized responses, producing near-linear associations in practice [14], [24], [31]. Taken together, the absence of curvature is consistent with modest marginal effects under high baseline access and with complementarity principles in which returns depend on co-investment in capabilities and standards rather than connectivity alone [29]. Evidence that logistics density raises e-commerce intensity further supports proportional, not explosive, responses in developed networks [45].

Robustness diagnostics address H3. Directional stability persists when excluding each country in turn and when altering the estimation window. Coefficients tend to be larger in windows emphasizing later years, consistent with the gradual diffusion of digital practices and improvements in network reliability. While robustness cannot substitute for causal identification, it reduces the likelihood that results are artifacts of influential cases or period choice—an issue noted in prior connectivity work [8], [17].

Dynamic checks inform H4. Lead placebos and one-period lags are small and statistically indistinct from zero, offering no evidence of strong anticipatory behavior or delayed effects that would overturn a contemporaneous reading. This aligns with the theory that improved connectivity reduces delivery risk and transaction frictions in real-time, modestly expanding the feasible e-sales frontier without requiring long adjustment lags [17], [48].

5.2 Interpretation of Functional and Dynamic Effects

These results are consistent with the World Bank Logistics Performance Index (LPI) assessment, which highlights that incremental enhancements in shipment timeliness and tracking technologies disproportionately benefit small and medium-sized enterprises (SMEs) engaged in cross-border e-commerce. The LPI highlights the crucial role of reliable supply chain connections and suggests that policies aimed at enhancing port and customs operations, alongside the digitalization of supply chains, can substantially improve these benefits [18].

5.3 Contributions

Theoretical Contribution. The study operationalizes physical–digital complementarity by linking an external resource (connectivity) to an internal capability (e-sales intensity), refining the Resource-Based View to emphasize returns contingent on infrastructure that firms cannot individually supply [5]. It also extends institutional arguments by treating the EU's TEN-T and Digital Single Market initiatives as complementary policy bundles [15]. Finally, it transforms the concept of complementarity from a theoretical claim into a testable empirical construct [29].

Methodological Contribution. Applying two-way fixed effects with Driscoll–Kraay inference [42], [43] demonstrates how robust panel designs can yield reliable macro-micro insights even under cross-sectional dependence. This procedure serves as a replicable template for future studies on logistics and digital commerce.

Methodological contribution. The work centers a firm-relevant intensity outcome (e-sales share) instead of macro aggregates, and embeds curvature, robustness, and dynamic probes as first-class diagnostics within a TWFE–Driscoll–Kraay architecture. The procedural template clean annualization of quarterly LSCI via medians, inner-join integration, LOCO, and window grids, and visual coefficient registries provides a replicable path for secondary data studies at the logistics–digital interface.

Applied contribution. For managers, results affirm that logistics reliability is part of the trust architecture of e-commerce: delivery predictability supports conversion and retention beyond marketing levers. For policymakers, the evidence supports coordinated portfolios—port and corridor upgrades alongside SME digitalization and cross-border facilitation—rather than siloed interventions [17], [30].

5.4 Integrative Discussion: Linking Evidence, Policy, and SDGs

The empirical evidence provides a measurable pathway through which maritime connectivity enhances digital and commercial outcomes. The baseline elasticity, approximately 0.018, indicates that a 100-point rise in the Liner Shipping Connectivity Index (LSCI) corresponds to roughly a 1.8-percentage-point increase in the share of turnover from e-sales. While numerically modest, this magnitude is meaningful in macroeconomic terms: for EU coastal economies with average digital turnover exceeding €200 billion annually, such an effect equates to nearly €3–4 billion in additional online trade value when physical connectivity improves by one standard deviation.

These findings hold implications that extend beyond firm performance. They signal that digital prosperity still travels along physical routes, and e-commerce growth depends on the same infrastructural backbone that underpins trade logistics. Consequently, the results justify integrated investment portfolios that combine port modernization, intermodal corridor development, and SME digitalization programs, rather than siloed initiatives. Such coordination directly supports Sustainable Development Goal 8 (Decent Work and Economic Growth) by stimulating employment through export-enabled SMEs, and Goal 9 (Industry, Innovation, and Infrastructure) by reinforcing resilient physical–digital linkages.

For policymakers, this evidence provides a quantitative basis for sequenced interventions: Phase 1 – Connectivity reliability: reduce customs variance, upgrade port tracking systems, and harmonize data exchange standards. Phase 2 – Digital Readiness: Expand SME onboarding, interoperability of payments, and consumer trust frameworks. Phase 3 – Integrated Monitoring: Institutionalize dual metrics, LSCI and e-sales turnover share, as co-indicators of progress toward SDGs 8 and 9.

For managers and platform operators, the findings reaffirm the importance of logistics reliability as part of the trust architecture of e-commerce: predictable delivery and transparent tracking directly translate into higher conversion rates and lower return ratios. Firms should therefore synchronize their digital strategies with improvements in local connectivity indices, aligning fulfillment capacity with market expansion.

In summary, the study's empirical model translates directly into actionable policy design: when digitalization and logistics reforms advance together, their combined marginal gains compound rather than substitute. This interdependence embodies the "twin transformation" imperative of the European Green and Digital Agendas, positioning maritime and digital infrastructures as mutually reinforcing engines of sustainable growth.

5.5 Recommendations

Integrated Investment Approach. Policymakers should treat maritime and digital infrastructure as co-dependent pillars of growth. Evidence from the EU suggests that bundled programs—port and corridor upgrade co-timed with SME digitalisation grants—generate greater multiplier effects than siloed initiatives [15], [16].

Coordination aligned with the Sustainable Development Goals (SDGs) notably advances SDG 8 (Decent Work and Economic Growth) and SDG 9 (Industry, Innovation, and Infrastructure) by linking job creation directly to productivity gains driven through enhanced connectivity. Institutionalizing real-time monitoring through analytic tools such as the World Bank's Logistics Performance Index (LPI) 2023 enables joint tracking of delivery reliability and e-commerce performance, which is critical for sustainable growth in emerging markets [18].

Strategic Sequencing. Early stages should aim to reduce delivery variance and customs delays; subsequent phases should focus on expanding digital onboarding, interoperable payments, and cross-border consumer trust mechanisms. This phased model ensures that connectivity gains translate into sustainable digital adoption.

Managerial Actions. For SMEs, align digital roadmaps with local connectivity trajectories. When LSCI improves, firms should enhance delivery promises, tracking integration, and customer experience systems. Partnerships with carriers and platforms can internalize external reliability gains, reducing volatility in fulfilment and returns.

Policy. Institutionalize joint planning between transport and digital programs. Concretely, pair TEN-T corridor enhancements, customs digitization, and tracking standards with SME onboarding, interoperable payments, and consumer-protection harmonization. Sequence interventions so that early reductions in delivery variability coincide with targeted SME e-commerce support, amplifying uptake. Improve measurement by publishing high-frequency indicators of delivery reliability (e.g., transit-time variance, failed-delivery rates) alongside LSCI to monitor complementarity in real time.

Managerial. Align digital roadmaps with connectivity trajectories. Where connectivity improves, commit to delivering on promises, providing richer tracking, and integrating OMS, carrier, and WMS to internalize external reliability gains. Prioritize products with favorable value-to-weight characteristics for early scaling; for bulky or fragile goods, emphasize pre-orders and scheduled delivery to manage logistics risk. Explore partnerships with carriers and platforms for SME-tailored tariffs and data sharing that stabilize demand forecasting.

5.6 Limitations

First, both focal measures are proxies. LSCI is an index of linear network position, not last-mile capacity; e-sales share aggregates across sectors and firm sizes. These choices enable coverage and comparability but abstract from the mechanism-level. Second, TWFE with robust inference mitigates confounding but does not establish causality. The absence of quasi-experimental shocks, instruments, or event times limits the strength of identification.

Third, scope matters. Europe features relatively high baseline connectivity and institutional harmonization; effects may differ in settings with sparse networks or volatile institutions. Finally, curvature tests are quadratic by design, and dynamic checks are parsimonious, potentially missing thresholds or richer adjustment paths; more flexible models risk overfitting without additional data.

5.7 Directions for Future Research

Broaden geography to test external validity and uncover nonlinearities where connectivity is low or changes are lumpy (e.g., selected ports coming online). Develop mechanism-sensitive indicators, such as on-time performance distributions, customs clearance variability, and parcel failure rates, at a monthly or quarterly frequency, and match them to e-commerce outcomes.

Advance causal identification via port expansions, strikes, policy timing, or network reroutings suitable for difference-in-differences, synthetic control, or instrumental-variable strategies. Build micro–macro linkages by matching firm-panel data (orders, returns, CX metrics) to geo-tagged logistics performance, adjudicating whether reliability or cost channels dominate. Finally, extend the complementarity frame to resilience and sustainability, integrating green ports, rail shifts, and digital twins as moderators of the connectivity–adoption link.

5.8 Conclusion

The findings offer a cautiously affirmative answer: within European countries, improvements in maritime connectivity are associated with incremental increases in e-sales intensity. Although effect sizes are modest, the consistency across robustness checks and temporal plausibility suggests a structural link between physical and digital infrastructures.

In policy language, digital prosperity still travels along physical routes. Investments that jointly strengthen logistics and digital capabilities transform linear progress into compound development—advancing both efficiency and inclusiveness under the SDG 8/9 mandate.

The study offers a cautiously affirmative answer: within European countries, improvements in maritime connectivity are associated with incremental increases in e-sales intensity. The relationship appears approximately linear over the period 2014–2024, is directionally robust across extensive checks, and is temporally plausible without strong pre-trends. Effect sizes are modest, but structure matters: small, persistent gains in connectivity can cumulate into meaningful digital commercialization when paired with complementary capabilities.

For scholarship, the contribution serves as an empirical bridge between physical networks and digital outcomes, raising the evidentiary bar with a transparent and replicable panel strategy. For practice, the message is practical and balanced: plan and invest jointly. In an era where the efficiency frontier has shifted from larger ships to more efficient systems, digital prosperity continues to travel along physical routes.

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References

[1] UNCTAD, Review of Maritime Transport 2024, 2024. https://unctad.org/publication/review-maritime-transport-2024.

[2] World Bank, Connecting to Compete 2023 : Trade Logistics in an Uncertain Global Economy, 2023. https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099042123145531599.

[3] J. Carballo, M. Rodriguez Chatruc, C. Salas Santa, C. Volpe Martincus, Online Business Platforms and International Trade, J. Int. Econ. 137 (2022), 103599. https://doi.org/10.1016/j.jinteco.2022.103599.

[4] J. Ballerini, D. Herhausen, A. Ferraris, How Commitment and Platform Adoption Drive the E-Commerce Performance of SMEs: A Mixed-Method Inquiry into E-Commerce Affordances, Int. J. Inf. Manag. 72 (2023), 102649. https://doi.org/10.1016/j.ijinfomgt.2023.102649.

[5] J. Barney, Firm Resources and Sustained Competitive Advantage, J. Manag. 17 (1991), 99-120. https://doi.org/10.1177/014920639101700108.

[6] European Commission, Europe's Digital Decade, 2025. https://digital-strategy.ec.europa.eu/en/policies/europes-digital-decade.

[7] OECD, OECD Digital for SMEs Global Initiative, 2025. https://www.oecd.org/en/networks/oecd-digital-for-smes-global-initiative.html.

[8] M. Fugazza, J. Hoffmann, Liner Shipping Connectivity as Determinant of Trade, J. Shipp. Trade 2 (2017), 1. https://doi.org/10.1186/s41072-017-0019-5.

[9] J. An, Maritime Logistics and Digital Transformation with Big Data: Review and Research Trend, Marit. Bus. Rev. 9 (2024), 229-242. https://doi.org/10.1108/mabr-10-2023-0069.

[10] Z. Raza, J. Woxenius, C.A. Vural, M. Lind, Digital Transformation of Maritime Logistics: Exploring Trends in the Liner Shipping Segment, Comput. Ind. 145 (2023), 103811. https://doi.org/10.1016/j.compind.2022.103811.

[11] OECD (2025), The Digitalisation of Trade Documents and Processes: Going Paperless Today, Going Paperless Tomorrow, OECD Trade Policy Papers, No. 297, OECD Publishing, Paris, https://doi.org/10.1787/64872f25-en.

[12] J. Basulo-Ribeiro, L. Teixeira, Industry 4.0 Supporting Logistics Towards Smart Ports: Benefits, Challenges and Trends Based on a Systematic Literature Review, J. Ind. Eng. Manag. 17 (2024), 492-515. https://doi.org/10.3926/jiem.6180.

[13] I. del Rosal, Maritime Connectivity and Agricultural Trade, J. Agric. Econ. 75 (2023), 153-168. https://doi.org/10.1111/1477-9552.12548.

[14] B. Belmoukari, J. Audy, P. Forget, Smart Port: A Systematic Literature Review, Eur. Transp. Res. Rev. 15 (2023), 4. https://doi.org/10.1186/s12544-023-00581-6.

[15] A. Burinskienė, M. Seržantė, Digitalisation as the Indicator of the Evidence of Sustainability in the European Union, Sustainability 14 (2022), 8371. https://doi.org/10.3390/su14148371.

[16] B. Bieszk-Stolorz, K. Dmytrów, Decent Work and Economic Growth in EU Countries—Static and Dynamic Analyses of Sustainable Development Goal 8, Sustainability 15 (2023), 13327. https://doi.org/10.3390/su151813327.

[17] UNCTAD, Liner Shipping Connectivity Index, Quarterly (Analytical), 2025. https://unctadstat.unctad.org/datacentre/dataviewer/US.LSCI.

[18] World Bank, Worldwide Governance Indicators, 2025. https://www.worldbank.org/en/publication/worldwide-governance-indicators.

[19] B. Tovar, A. Wall, The Relationship Between Port-Level Maritime Connectivity and Efficiency, J. Transp. Geogr. 98 (2022), 103213. https://doi.org/10.1016/j.jtrangeo.2021.103213.

[20] IATA, Air Cargo Market Analysis-December 2022, 2022. https://www.iata.org/en/iata-repository/publications/economic-reports/air-cargo-market-analysis---december-2022.

[21] ATAG, Aviation: Benefits Beyond Borders 2024, 2024. https://aviationbenefits.org/downloads/aviation-benefits-beyond-borders-2024.

[22] European Commission, Trans-European Transport Network (TEN-T). https://transport.ec.europa.eu/transport-themes/infrastructure-and-investment/trans-european-transport-network-ten-t_en

[23] European Council, Trans-European Transport Network (TEN-T): Council Gives Final Green Light to New Regulation Ensuring Better and Sustainable Connectivity in Europe, 2024. https://www.consilium.europa.eu/en/press/press-releases/2024/06/13/trans-european-transport-network-ten-t-council-gives-final-green-light-to-new-regulation-ensuring-better-and-sustainable-connectivity-in-europe.

[24] Y. Yang, Y. Hsieh, The Critical Success Factors of Smart Port Digitalization Development in the Post-COVID-19 Era, Case Stud. Transp. Polic. 17 (2024), 101231. https://doi.org/10.1016/j.cstp.2024.101231.

[25] M. Christopher, Supply Chain Management, Pearson/FT Publishing, 2023.

[26] D.J. Bowersox, D.J. Closs, Logistical Management: The Integrated Supply Chain Process, McGraw-Hill, 1996.

[27] J. López González, S. Sorescu, P. Kaynak, Of Bytes and Trade: Quantifying the Impact of Digitalisation on Trade, OECD Trade Policy Papers, No. 273, OECD Publishing, Paris, (2023). https://doi.org/10.1787/11889f2a-en.

[28] European Commission, Provisional Agreement on More Sustainable and Resilient Trans-European Transport Network Brings Europe Closer Together, https://transport.ec.europa.eu/news-

events/news/provisional-agreement-more-sustainable-and-resilient-trans-european-transport-network-brings-europe-2023-12-19_en.

[29] P. Milgrom, J. Roberts, Complementarities and Fit Strategy, Structure, and Organizational Change in Manufacturing, J. Account. Econ. 19 (1995), 179-208. https://doi.org/10.1016/0165-4101(94)00382-f.

[30] OECD, OECD Digital Economy Outlook 2024 (Volume 1): Embracing the Technology Frontier, OECD Publishing, Paris, (2024). https://doi.org/10.1787/a1689dc5-en.

[31] G. Soava, A. Mehedintu, M. Sterpu, Analysis and Forecast of the Use of E-Commerce in Enterprises of the European Union States, Sustainability 14 (2022), 8943. https://doi.org/10.3390/su14148943.

[32] N.L.P. Indiani, J.S. Keshminder, N.I. Wiratama, G.S. Amertha, Unlocking E-Commerce Potential in SMEs: An Integrative Framework for Adoption in Emerging Markets, Humanit. Soc. Sci. Commun. 12 (2025), 766. https://doi.org/10.1057/s41599-025-04952-3.

[33] J. Ballerini, D. Herhausen, A. Ferraris, How Commitment and Platform Adoption Drive the E-Commerce Performance of SMEs: A Mixed-Method Inquiry into E-Commerce Affordances, Int. J. Inf. Manag. 72 (2023), 102649. https://doi.org/10.1016/j.ijinfomgt.2023.102649.

[34] L.U. Ashrapova, R.E. Yakhshiboyev, The Rise of Digital Marketplaces and Their Role in Small Business Globalization, Int. Sci. J. Pioneer. Stud. Theor. 1 (2025), 17-20. https://doi.org/10.5281/zenodo.15046107.

[35] Y. Abukari, R. Saluja, Economic Impact of Digitalization on SME Internationalization, Interdiscip. J. Afr. Alliance Res. Advocacy Innov. (2025). https://doi.org/10.64261/ijaarai.v1n2.010.

[36] E. Salamah, A. Alzubi, A. Yinal, Unveiling the Impact of Digitalization on Supply Chain Performance in the Post-COVID-19 Era: The Mediating Role of Supply Chain Integration and Efficiency, Sustainability 16 (2023), 304. https://doi.org/10.3390/su16010304.

[37] O.E. Williamson, The Economic Institutions of Capitalism: Firm, Markets, Relational Contracting, Free Press, 1985.

[38] E.M. Rogers, Diffusion of Innovations, Free Press, (2003).

[39] F.D. Davis, Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology, MIS Q. 13 (1989), 319-340. https://doi.org/10.2307/249008.

[40] D. Ivanov, A. Dolgui, Stress Testing Supply Chains and Creating Viable Ecosystems, Oper. Manag. Res. 15 (2021), 475-486. https://doi.org/10.1007/s12063-021-00194-z.

[41] W. Wang, Y. Peng, X. Xu, et al., Smart Container Port Development: Recent Technologies and Research Advances, Intell. Transp. Infrastruct. 3 (2023), liad022. https://doi.org/10.1093/iti/liad022.

[42] D. Hoechle, Robust Standard Errors for Panel Regressions with Cross-Sectional Dependence, Stata J.: Promot. Commun. Stat. Stata 7 (2007), 281-312. https://doi.org/10.1177/1536867x0700700301.

[43] J.C. Driscoll, A.C. Kraay, Consistent Covariance Matrix Estimation with Spatially Dependent Panel Data, Rev. Econ. Stat. 80 (1998), 549-560. https://doi.org/10.1162/003465398557825.

[44] B. Djordjević, A. Ståhlberg, E. Krmac, A.S. Mane, B. Kordnejad, Efficient Use of European Rail Freight Corridors: Current Status and Potential Enablers, Transp. Plan. Technol. 47 (2023), 62-88. https://doi.org/10.1080/03081060.2023.2294344.

[45] S. Zeng, Q. Fu, F. Haleem, Y. Han, L. Zhou, Logistics Density, E-Commerce and High-Quality Economic Development: An Empirical Analysis Based on Provincial Panel Data in China, J. Clean. Prod. 426 (2023), 138871. https://doi.org/10.1016/j.jclepro.2023.138871.

[46] Z. Su, Y. Liu, Y. Gao, K. Park, M. Su, Critical Success Factors for Green Port Transformation Using Digital Technology, J. Mar. Sci. Eng. 12 (2024), 2128. https://doi.org/10.3390/jmse12122128.

[47] P.J. DiMaggio, W.W. Powell, The Iron Cage Revisited: Institutional Isomorphism and Collective Rationality in Organizational Fields, Am. Sociol. Rev. 48 (1983), 147. https://doi.org/10.2307/2095101.

[48] K.B. Hendricks, V.R. Singhal, The Effect of Supply Chain Glitches on Shareholder Wealth, J. Oper. Manag. 21 (2003), 501-522. https://doi.org/10.1016/j.jom.2003.02.003.