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A Portfolio-First Public-Data Framework for EU-27 Cross-Border E-Commerce Market-Entry Screening

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Abstract

Cross-border e-commerce in the European Union remains operationally heterogeneous despite Digital Single Market integration, which complicates first-stage market comparison. This study develops a portfolio-first public-data framework for EU-27 cross-border e-commerce market-entry screening using 2023 as the common reference year. The framework derives PC1_EF, a PCA-derived execution-condition screening axis, from enterprise e-sales penetration, a digital financial participation proxy and the World Bank Logistics Performance Index. Market potential is calculated by multiplying the population aged 16–74 by online-shopping incidence, while cross-border buying openness remains a separate demand-side overlay. The first component explains 67.84% of backbone variance, with all loadings being positive. The portfolio distinguishes country positions across execution conditions, market scale and cross-border openness. Auxiliary rule-based screening bands serve as a compact summary. PC1_EF is positively associated with enterprise-side e-commerce turnover intensity (Spearman $\rho = 0.486$, $p = 0.014$, $N = 25$), providing partial criterion-consistency evidence. GDP_PPS rank differences provide interpretive context. Equal-weight and leave-one-variable-out checks assess the sensitivity of the continuous ordering, while LPI gate-family and no-LPI/no-gate checks assess the sensitivity of the band summaries. The framework provides a transparent and reproducible basis for comparing EU-27 cross-border e-commerce markets.

Keywords: cross-border e-commerce; Digital Single Market; EU-27; market screening; execution conditions; principal component analysis; logistics performance; market potential; international market selection; decision support



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1. Introduction

Although the European Union has worked for years to build an integrated Digital Single Market, cross-border e-commerce (CBEC) still operates unevenly across member states [1,2]. Online trade can lower some distance-related costs, but it has not removed language barriers, delivery problems, payment frictions or home-market bias in cross-border transactions [2–4]. Evidence from consumer behavior points the same way. The likelihood that people buy online from another EU country differs substantially from one member state to another, and these differences reflect country-level conditions as well as

individual characteristics [5]. For firms, the EU therefore offers an integrated legal and policy space, but not a uniform operating environment for cross-border e-commerce.

This persistent heterogeneity matters for first-stage market-entry decisions. Firms considering cross-border e-commerce expansion do not face differences in scale alone. They also face differences in logistics capability, enterprise digital-sales penetration, digitally mediated financial participation and buyer-side openness to cross-border purchasing. These dimensions do not always move together. Supply-side evidence from the EU Digital Single Market shows that cross-border orders have materially weaker fulfillment outcomes than domestic orders. Delivery costs, supplier restrictions, dispute-resolution costs and knowledge of foreign rules remain important barriers, especially for smaller firms [6,7]. Logistics adds a further constraint. Distance still matters in EU cross-border e-commerce, and delivery design affects how firms reduce both time-related and perceived distance for buyers [8]. At the macro level, international logistics is also associated with cross-border e-commerce trade over longer horizons [9].

This uneven landscape creates a practical screening problem. Country-level research shows that e-commerce development is shaped by technological, institutional and socio-economic conditions [10–15]. International market selection research makes a related point: market choice is usually a staged filtering process in which opportunity, constraint and fit must be considered together, rather than reduced to a single score [16–19]. The Digital Economy and Society Index (DESI) and the United Nations Conference on Trade and Development (UNCTAD) business-to-consumer (B2C) E-commerce Index are useful system-level monitoring tools [20,21]. They do not, however, organize country comparison as a market-entry portfolio that keeps execution conditions, market scale and cross-border openness analytically separate. Recent evidence published in *JTAER* also confirms the role of financial development and information and communication technology (ICT) infrastructure in e-commerce adoption, but does not address the narrower EU-27 screening problem under a unified public-data design [22].

To address this gap, the study develops a cross-sectional screening framework for EU-27 cross-border e-commerce markets using 2023 as the common reference year. At the time of extraction, 2023 was the most recent year for which the selected public indicators could be assembled coherently. The framework is portfolio-first rather than ranking-first. It uses principal component analysis (PCA) to derive an execution-condition screening axis from a compact backbone composed of enterprise e-sales penetration, digital financial participation and logistics capability. Market potential and cross-border buying openness are kept outside that axis as separate overlays, so that execution conditions, market scale and demand-side openness remain visible in the same screening space. Market potential is measured using the population aged 16–74 and online-shopping incidence. Enterprise-side e-commerce turnover intensity is used as a constrained criterion-consistency check, while GDP per capita in purchasing power standards is used as a prosperity-association and rank-difference diagnostic. In this setting, PCA provides a transparent summary of shared variation among the retained public-data indicators and keeps the framework distinct from a broad readiness-index exercise [23,24].

The study addresses three research questions and one technical objective.

RQ1: Can a compact public-data backbone built from enterprise e-sales penetration, digital financial participation and logistics capability support an interpretable PCA-derived execution-condition screening axis for the first-stage comparison of EU-27 cross-border e-commerce markets?

RQ2: Does a portfolio-first design that keeps execution conditions, market potential and cross-border buying openness analytically separate yield interpretable country positions for first-stage CBEC market comparison?

RQ3: How do the criterion-consistency, prosperity-association and sensitivity diagnostics qualify the interpretation of the PCA-derived screening axis within the public-data constraints of the study?

Technical objective: To assess the sensitivity of the continuous country ordering under equal-weight and leave-one-variable-out checks, and the sensitivity of the auxiliary screening bands under the retained rank-aware Logistics Performance Index (LPI) gate and no-LPI/no-gate variants.

The study contributes to the literature by offering a transparent EU-27 public-data screening architecture that preserves the distinction between execution conditions, market scale and cross-border openness. It is designed to support upstream comparison before firm-specific, product-specific and channel-specific evaluation.

The remainder of the article is structured as follows. Section 2 reviews the literature on EU cross-border e-commerce heterogeneity, structural barriers, country-level e-commerce development and international market selection. Section 3 presents the data, variable construction and analytical framework. Section 4 reports the empirical results, including the screening portfolio, criterion-consistency evidence and diagnostic and sensitivity results. Section 5 discusses the implications and limitations of the findings for first-stage EU cross-border e-commerce market screening. Section 6 concludes.

2. Literature Review

2.1. EU Cross-Border E-Commerce Heterogeneity

The literature on European e-commerce does not support the idea that the European Union can be treated as a single, operationally uniform CBEC market. Early work on the Digital Single Market already showed that online cross-border trade in goods remained constrained by language, delivery, payment frictions and home-market bias, even when digital channels reduced some traditional distance costs [3,4]. More recent evidence points in the same general direction from the consumer side. Cross-border purchasing differs substantially across European countries, and these differences cannot be explained by individual-level characteristics alone. Research also shows that country-level conditions still shape consumers' movement from domestic online buying to cross-border purchasing within Europe [5].

This broader pattern appears in the cross-country development literature on European e-commerce. Across Europe, e-commerce growth, digital adoption and online-shopping behavior have not followed one common path. National e-commerce growth depends on different combinations of internal and external drivers [12], and longer-run e-commerce development also varies meaningfully from one European country to another [13]. The evidence on the EU digital divide and on the spatial distribution of e-commerce points in the same direction: European e-commerce remains uneven, not only across consumers, but also across places [15,25,26]. Taken together, this literature supports the paper's starting premise that first-stage market-entry screening should account for heterogeneity rather than presuppose homogeneity.

2.2. Barriers, Frictions and the Distinction Between Execution Conditions and Cross-Border Openness

A second literature stream shows that cross-border e-commerce in Europe is shaped by a layered set of frictions on both the supply and demand sides. European firms face a mix of regulatory, market, financial and information barriers in cross-border online trade [27–29]. On the supply side, cross-border orders face materially lower success rates than domestic orders, with shared language, product characteristics and distribution restrictions that affect whether firms actually serve foreign buyers online [6]. Firm-level evidence from the Digital Single Market identifies several important barriers to cross-border

online activity. These include delivery costs, supplier restrictions, dispute-resolution costs, taxation rules and knowledge of foreign rules, which affect smaller firms particularly strongly [30–32]. Consumer-side evidence points in the same direction: price and variety can attract consumers across borders, but perceived risk and transaction frictions still hold them back [33,34].

Logistics deserves separate emphasis because it is treated here as part of execution conditions, not as background context. Distance continues to matter in EU cross-border e-commerce, and delivery design, especially express delivery, can reduce time-related and psychological distance [8,35,36]. At the macro level, logistics performance is associated with cross-border e-commerce trade over the longer term, although short-run dynamics are less uniform [9,37]. Logistics is therefore treated here as part of the retained backbone rather than as a standalone outcome. This reading is also consistent with work that frames customs, border procedures, logistics services, infrastructure and information systems as key building blocks of cross-border e-commerce performance [38]. For country-level measurement, the 2023 Logistics Performance Index is built from customs, infrastructure, international shipments, logistics competence, tracking and tracing, and timeliness, making it a defensible logistics-capability signal for first-stage screening [39]. Related European panel evidence also shows that logistics capability is tied to broader macro-structural conditions, such as income, trade connectivity and service integration, rather than functioning as a purely technical delivery variable [40]. LPI therefore contributes to the retained backbone, while cross-border buying openness remains a separate behavioral overlay.

Institutional and regulatory frictions add another layer. The Commission's sector inquiry documented contractual restrictions, platform restrictions and geo-blocking practices that could still obstruct online cross-border access within the EU [41]. The later short-term review of the Geo-blocking Regulation reported some improvement in website access and rerouting practices, but it also showed that reluctance to offer cross-border delivery was still an important practical constraint [42,43]. Related JRC evidence also shows that delivery costs are a measurable constraint on intra-EU cross-border e-commerce flows, adding a concrete execution-side friction to the regulatory evidence [44]. This institutional picture is also consistent with the Consumer Conditions Scoreboard, which monitors the conditions under which consumers participate in the Single Market and highlights the persistence of cross-border confidence gaps and consumer-side frictions [45,46]. The broader Digital Single Market policy literature points in the same direction: policy integration is substantial, but it still does not eliminate practical asymmetries across national markets [47]. Taken together, these studies indicate that country-level screening remains relevant even within an integrated policy space.

Trust, consumer protection and payment-related frictions are more closely related to transactional confidence and cross-border openness than to country-level execution conditions. The relevance of payment systems and language-related frictions in EU cross-border e-commerce has already been noted in the literature [3]. Payment-related issues and limited transaction-side confidence can create practical frictions in online commerce, while trustmark arrangements may help address those concerns [3,48–54]. Consumer protection has likewise been linked to e-commerce turnover in Europe, while some structural macroeconomic variables appear less decisive than often assumed [55]. Consumer-protection arrangements have also been shown to affect trust and cross-border purchasing behavior in the EU [56,57]. This consumer-side literature is also consistent with individual-level evidence from Spain, where digital skills, education, online reviews and foreign nationality are all associated with cross-border e-commerce behavior [58]. In the present study, these strands help interpret cross-border openness and confidence without merging them into

the same screening axis as enterprise e-sales penetration, digital financial participation and logistics capability.

2.3. Country-Level E-Commerce Development and Adoption

A third stream of research examines national differences in e-commerce development. It is especially relevant where it links those differences to macro-structural conditions that can inform first-stage screening. European studies associate e-commerce development with varying technological, institutional and socio-economic conditions, supporting the use of country-level indicators in this setting [10–13].

EU-level evidence linking internet-banking use and related digital financial behavior to e-commerce development helps contextualize the digital financial participation proxy (DFP) [11]. In this framework, DFP is a country-level proxy for digital financial participation. It is not a direct measure of enterprise payment readiness, checkout design, gateway architecture or institutional trust. Broader multi-country and European panel studies associate financial development, ICT conditions and trust-related national environments with e-commerce adoption and transaction intensity [22,59].

Enterprise-focused adoption studies also support the use of enterprise e-sales penetration (ESP) as part of the retained backbone. E-business adoption by European firms depends on a mix of technological, organizational and environmental facilitators [60]. B2B e-commerce across Europe can also be understood as moving from adoption toward routinization rather than remaining a binary condition [61]. European countries also differ materially in the e-commerce functionalities present on enterprise websites, and similar e-commerce profiles do not map neatly onto general economic or digital development [62]. Together, these studies support using enterprise e-sales penetration as a country-level signal of digital-sales activity. ESP does not, however, isolate cross-border B2C e-commerce or capture the full breadth of national e-commerce development.

2.4. International Market Selection, Market Screening and Portfolio-First Logic

The paper's main conceptual anchor comes from the international market selection literature, alongside the broader e-commerce development literature. This literature treats market selection as a distinct strategic problem that involves screening, identifying and prioritizing potential foreign markets under resource constraints. Screening, identification and selection have been described as distinct stages in foreign-market evaluation [18]. Market selection and segmentation have also been framed as structured filtering problems shaped by multiple dimensions of attractiveness and fit [17,19]. More recent work continues to treat market, network and opportunity selection as strategic filtering problems rather than scoreboard exercises [16].

This literature also provides the basis for positioning the framework proposed here. The framework is designed for first-stage screening rather than full market-entry optimization. In that setting, a portfolio-first logic is more informative than a single composite league table. This positioning is consistent with evidence that online retailers consider market size, rule of law, local market knowledge, common language and logistics performance when selecting foreign markets [63]. This evidence supports preserving the dimensions separately because they do not necessarily move together.

2.5. Enterprise-Side Turnover and Criterion-Consistency Logic

The enterprise-side literature is relevant here in a focused role: it helps connect country-level execution conditions with enterprise-side e-commerce activity. A useful anchor is the evidence that e-commerce turnover in Europe is linked to policy and institutional factors, especially consumer protection, rather than being a simple by-product of wealth [55]. These findings motivate the ETI criterion-consistency check while keeping its role appropriately limited.

Other enterprise-side sources strengthen this interpretation without changing the role of ETI in the framework. Enterprise e-commerce capacity differs across European countries and does not map linearly onto general digital development [62]. Enterprise adoption can also be understood as a staged process rather than a binary condition [61]. Recent research on social capital and trust provides additional context for the role of national trust environments in e-commerce adoption and transaction intensity [59]. These studies are most useful for contextualizing enterprise heterogeneity across countries. In this study, ETI remains a source-limited enterprise-side criterion-consistency check.

2.6. Methodological Positioning of the Framework

PCA is used here as a dimension-reduction tool within a focused first-stage CBEC framework under public-data constraints [23]. This application is consistent with composite-indicator guidance that aggregation should follow the decision purpose rather than collapse distinct dimensions automatically [24]. The retained component, denoted PC1_EF, provides a transparent screening axis for comparing EU-27 country positions in 2023; broader readiness, prediction and firm-level success questions remain outside the study's scope.

Broad policy scoreboards and e-commerce readiness instruments, such as the DESI and the UNCTAD B2C E-commerce Index, are useful for benchmarking and monitoring at system level [20,21,64]. The present framework addresses a narrower first-stage screening problem. It keeps execution conditions, market potential and cross-border buying openness analytically separate so that structural conditions are not conflated with market scale or demand-side behavior. In this sense, the paper contributes a compact and interpretable screening space for first-stage CBEC market comparison across the EU-27.

3. Methods

3.1. Research Design and Scope

This study develops a cross-sectional screening framework for first-stage market-entry assessment in EU cross-border e-commerce for the 2023 reference year. The unit of analysis is the country, and the empirical domain covers the 27 member states of the European Union. The design follows a portfolio-first logic. The framework is designed to position markets in a structured screening space rather than to produce a universal readiness index or a deterministic country league table. It preserves the distinction between execution conditions, market scale and cross-border demand-side openness.

The methodological architecture separates four roles. First, PC1_EF summarizes the compact structural backbone for first-stage comparison; its interpretation remains tied to the retained indicators and supporting diagnostics. Second, market potential and cross-border buying openness are retained as overlays outside the axis. Third, one enterprise-side turnover variable is used as a constrained criterion-consistency check. Fourth, GDP per capita in purchasing power standards is used as a prosperity-association and rank-difference diagnostic. It is not treated as proof that the screening axis is conceptually independent of national prosperity. This separation is maintained throughout the analysis.

The analysis is cross-sectional and uses 2023 as the common reference year. This choice follows the structure of the retained public-data inputs: the retained backbone requires a coherent single-year vintage, while the logistics variable does not provide a clean annual EU-27 panel for the study design. The framework is therefore built on one harmonized public-data cross-section rather than on temporally mixed observations.

3.2. Data Sources and Variable Operationalization

All variables were extracted from official public statistical sources. Eurostat series were assembled through a dedicated programmatic workflow, and the 2023 Logistics

Performance Index values were integrated from the fixed World Bank 2023 release used in the analytical dataset for this study [39]. The study uses seven variables, each assigned a defined analytical role within the framework.

The retained backbone contains three variables:

Enterprise e-sales penetration (ESP) measures the share of enterprises with ten or more persons employed whose electronic sales account for at least one percent of total turnover (Eurostat isoc_ec_esels, indicator E_AESELL) [65]. In this study, ESP is interpreted as a macro-level enterprise digital-sales penetration measure. It is not treated as a pure B2C online retail variable, because the underlying enterprise survey captures digital sales structures more broadly.

Digital financial participation (DFP) is extracted from Eurostat dataset tin00099, indicator I_IUBK, which captures internet-banking use among individuals aged 16–74 [66]. DFP is included as a country-level proxy for digital financial participation. It is not interpreted as a direct measure of enterprise payment readiness, payment-gateway integration, checkout architecture or institutional trust.

The Logistics Performance Index (LPI) is the 2023 World Bank overall logistics score, derived from six dimensions (customs, infrastructure, international shipments, logistics competence, tracking and tracing, and timeliness) [39]. LPI is used as a macro-level indicator of national logistics capability relevant to cross-border e-commerce execution. Its scope is limited to national logistics capability; parcel-level delivery performance and e-commerce courier density fall outside the measure.

Two variables are retained strictly as overlays:

Cross-border buying openness (CBO) is extracted from the Eurostat dataset isoc_ec_ibos, indicator I_BPG_EU, which captures the share of individuals purchasing online from sellers in other EU countries [67]. CBO is treated as a demand-side openness signal. It is not part of the PCA-derived execution-condition screening axis. This separation is intentional because behavioral openness is conceptually distinct from enterprise digital-sales penetration, digital financial participation and logistics capability.

Market potential (MP) is an overlay intended to express the approximate scale of the online consumer base in each country. It is operationalized as a deterministic combination of the population aged 16–74 from Eurostat demo_pjan [68] and an online-shopping incidence rate from Eurostat tin00096, indicator I_BLT12 [69]. The 2023 extraction constructs the population denominator by summing the single-year age rows Y16 through Y74 for all EU-27 countries. The filters are sex = T, unit = NR, freq = A and time = 2023. This age-consistent denominator is used for the main MP variable, whose formal construction is reported in Equation (3). A total-population MP variant is retained only for rank-stability support and is not used as the MP measure in the main portfolio.

One enterprise-side variable is retained for consistency checking:

E-commerce turnover intensity (ETI) is drawn from the Eurostat dataset isoc_ec_evals, indicator E_AWSVAL, with PC_TURN used as the primary extraction unit and PC_ETURN checked as a fallback extraction unit [70]. ETI is the only enterprise-side outcome signal retained for the consistency check. Its usable 2023 sample contains 25 countries; Luxembourg and Romania are unavailable in this extraction and are therefore disclosed as missing observations. ETI is therefore treated as a source-limited enterprise-side criterion-consistency check.

Finally, GDP per capita in purchasing power standards (GDP_PPS) is extracted from Eurostat dataset tec00114, indicator VI_PPS_EU27_2020_HAB [71]. GDP_PPS is used only as a prosperity-association and rank-difference diagnostic. It does not enter the backbone, the overlays or the screening-band construction.

3.3. Execution-Condition Screening-Axis Construction

The PCA-derived execution-condition screening axis is constructed from the three backbone variables, ESP, DFP and LPI. Because these variables are observed on different scales, they are first standardized across the EU-27 cross-section. For country i and variable j , the standardized value is

$$z_{ij} = \frac{x_{ij} - \mu_j}{\sigma_j} \quad (1)$$

where x_{ij} is the observed value, μ_j is the sample mean and σ_j is the standard deviation of variable j .

Principal component analysis (PCA) is then applied to the standardized backbone matrix as a dimension-reduction procedure for summarizing shared variation among the retained inputs [23]. Only the first principal component is retained. In generic form, the PCA-derived execution-condition screening score for country i can be written as

$$PC1_EF_i = w_{ESP}z_{i,ESP} + w_{DFP}z_{i,DFP} + w_{LPI}z_{i,LPI} \quad (2)$$

where w_{ESP} , w_{DFP} and w_{LPI} are the PCA-derived loadings.

This synthesis rule avoids arbitrary hand weighting and lets the covariance structure of the observed 2023 backbone inform the screening axis. This choice is consistent with guidance on composite-indicator construction when aggregation is intended to reflect empirical structure rather than subjective weighting choices [24]. The sign of the retained component is oriented so that higher values indicate stronger execution conditions in the 2023 public-data design. Explained variance, component loadings and the condition number are reported in the Results section. Additional PCA transparency diagnostics are reported in Appendix Table A4. Figure 1 provides a schematic overview of the complete analytical workflow.

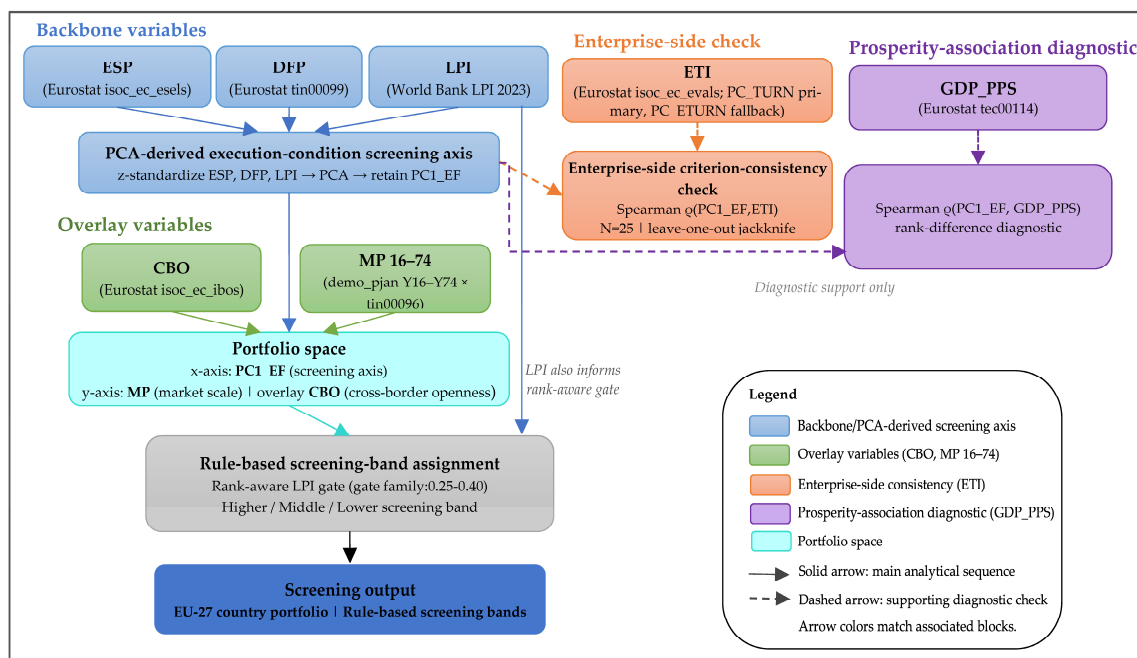


Figure 1. Analytical workflow of the EU-27 CBEC screening framework. PC1_EF is derived via PCA from z-standardized ESP, DFP and LPI, and is interpreted as a PCA-derived execution-condition screening axis. MP uses the population aged 16–74 and online-shopping incidence, while CBO is retained as a separate overlay. ETI is used for a criterion-consistency check, GDP_PPS is used for a prosperity-association diagnostic and the screening output is expressed as rule-based screening bands.

To make the PCA step transparent, the analysis reports the Pearson correlation matrix for ESP, DFP and LPI, together with Kaiser–Meyer–Olkin (KMO) and Bartlett diagnostics. These diagnostics are treated as transparency checks for a small EU-27, three-variable PCA, not as decisive evidence of construct validity. The detailed correlation, KMO and Bartlett results are reported in Appendix Table A4.

As an aggregation-rule sensitivity check, the PCA-derived score is compared with an equal-weight standardized composite of ESP, DFP and LPI. This comparison assesses whether the country ordering is materially dependent on the PCA aggregation rule and is used as a sensitivity check rather than as a claim of PCA superiority. Detailed results are reported in Appendix Table A5.

Leave-one-variable-out PCA checks are also reported. These checks re-estimate the first component after dropping ESP, DFP or LPI in turn. The no-DFP variant is treated as a specific proxy-sensitivity check because DFP captures individual internet-banking use as a country-level signal of digital financial participation, not direct enterprise payment readiness. The no-LPI variant is treated as a specific logistics and dual-use sensitivity check. Detailed results are reported in Appendix Table A5.

3.4. Portfolio Structure and Market-Potential Overlay

The study uses a portfolio representation rather than a single composite league table. The horizontal axis is the PCA-derived execution-condition screening axis, PC1_EF. The vertical axis is market potential (MP) computed with the age-consistent 16–74 population denominator. Cross-border buying openness (CBO) is retained as an interpretive overlay rather than a backbone input. This produces a three-part reading of each country: structural execution conditions, market scale and demand-side cross-border openness.

Market potential is constructed as

$$MP_{16-74,i} = Pop_{16-74,i} \times \frac{Inc_i}{100} \quad (3)$$

where $Pop_{16-74,i}$ is the population aged 16–74 for country i , constructed from Eurostat demo_pjan [68] by summing single-year ages Y16 through Y74; and Inc_i is the online-shopping incidence rate from Eurostat tin00096, indicator I_BLT12 [69].

The portfolio structure is used because it preserves decision-relevant distinctions that would be obscured in a single ranking. A country may display strong execution conditions but limited scale, or high scale but weaker structural execution conditions. Similarly, a country may be behaviorally open to cross-border e-commerce while still exhibiting weaker operational conditions. Keeping CBO and MP outside the backbone helps preserve those differences rather than compressing them into one composite score.

Screening bands are derived from the portfolio as rule-based aids for first-stage interpretation. The portfolio remains the primary empirical output.

The baseline banding rule is implemented in two steps. First, countries are sorted by LPI, then by PC1_EF and country code, and the lower LPI block defined by the baseline rank-aware gate is assigned to the lower screening band. With 27 countries and the baseline one-third gate, this assigns nine countries to the lower screening band. Second, the remaining countries are split by the median PC1_EF score into higher and middle screening bands. The labels are higher screening band, middle screening band and lower screening band, and are intended as screening-band summaries for early comparison.

3.5. Enterprise-Side Criterion-Consistency Check

The enterprise-side check examines whether higher PC1_EF positions are associated with greater e-commerce turnover intensity. Spearman's rank correlation is used because

ETI is only available for 25 countries and may exhibit non-normality and tied ranks. The coefficient, p -value and sample size are reported as a diagnostic finding. Because ETI is conceptually related to enterprise e-commerce activity, the association is interpreted as partial criterion-consistency evidence rather than external validation.

To assess whether the observed association depends on a single country, the analysis applies a leave-one-out jackknife across the 25 observations. Each iteration excludes one country and recomputes the rank-based association. The full results are reported in Appendix Table A2.

3.6. Diagnostic and Screening-Band Sensitivity Checks

Additional diagnostic and sensitivity checks are used to support interpretation. These checks do not enter backbone construction and do not replace the portfolio as the primary empirical output.

First, Spearman rank correlation measures the association between PC1_EF and GDP_PPS to assess whether the screening order resembles a simple prosperity ordering. Country-level rank differences identify where the two orders diverge. These comparisons provide interpretive context but do not establish conceptual independence from prosperity.

Second, the study evaluates the sensitivity of the screening bands under alternative gate settings. LPI has a dual role in the design: it enters the backbone and also informs the rank-aware gate used for the lower screening band. To avoid a brittle decimal-threshold logic, the banding rule is examined across a rank-aware LPI gate family rather than interpreted as a single hard cut-off. The tested gate fractions are 0.25, 0.30, one-third, 0.35 and 0.40, and the resulting screening-band assignments are compared with the baseline configuration. The results are interpreted as sensitivity evidence for the rule-based banding procedure. Detailed LPI gate-family results are reported in Appendix Table A3.

Because LPI enters both the backbone and the rank-aware gate, an additional no-LPI/no-gate sensitivity is reported. This check compares the baseline screening bands with PC1-only tertile bands and with tertile bands derived from a no-LPI backbone. Its purpose is to show how stable the band membership is when the LPI gate is removed or when LPI is removed from the backbone. Detailed results are reported in Appendix Table A6.

The equal-weight comparison and leave-one-variable-out PCA checks are summarized in the main diagnostic table and reported in detail in Appendix Table A5. The main diagnostic table reports compact summary findings only; detailed supporting evidence for the diagnostic and sensitivity checks is reported in Appendix Tables A1–A6.

4. Results

For the 2023 cross-section, the retained backbone variables and the overlay variables are observed for all EU-27 member states. Market potential is computed with the age-consistent population aged 16–74 denominator described in Section 3.4. A total-population MP variant is retained only for rank-stability support and is not used as the MP measure in the main portfolio. The ETI-based enterprise-side criterion-consistency check is available for 25 countries; Luxembourg and Romania are unavailable in this extraction and are disclosed as missing observations. This section therefore reports the continuous portfolio as the primary empirical output, with rule-based screening bands and diagnostic checks used as supporting interpretation.

4.1. PCA-Derived Execution-Condition Screening Axis

The first component, denoted PC1_EF, explained 67.84% of total backbone variance. All three inputs loaded positively, with DFP, ESP and LPI contributing in the same direction. The standardized backbone matrix had a condition number of approximately 2.44. PC1_EF

is therefore reported as a PCA-derived execution-condition screening axis for first-stage comparison. Table 1 summarizes the retained PCA backbone diagnostics, while Appendix Table A4 presents the correlation, KMO and Bartlett transparency checks.

Table 1. PCA backbone diagnostics for the retained execution-condition screening axis.

Metric	Value	Role in Analysis
Explained variance ratio (PC1)	0.6784	PC1 retained as compact screening axis
Condition number (standardized backbone)	2.4395	Collinearity check
ESP loading	0.5868	Positive backbone contribution
DFP loading	0.6173	Positive contribution; proxy interpreted cautiously
LPI loading	0.5240	Positive contribution; dual role assessed separately

4.2. EU-27 Screening Portfolio and Rule-Based Screening Bands

The central empirical output is the EU-27 screening portfolio, in which PC1_EF defines the horizontal axis, and market potential, estimated using the population aged 16–74 and online-shopping incidence, defines the vertical scale. Cross-border buying openness remains outside the backbone and is reported as a separate demand-side overlay. This structure preserves the distinction between execution conditions, market scale and cross-border openness, rather than compressing all three dimensions into a single league table.

Using the baseline rule-based banding procedure, the portfolio is summarized into three neutral screening bands. The lower screening band is defined by the rank-aware LPI gate, while the remaining countries are split by the median PC1_EF score into higher and middle screening bands. The bands provide a compact first-stage summary and are interpreted together with the continuous country positions shown in Figure 2.

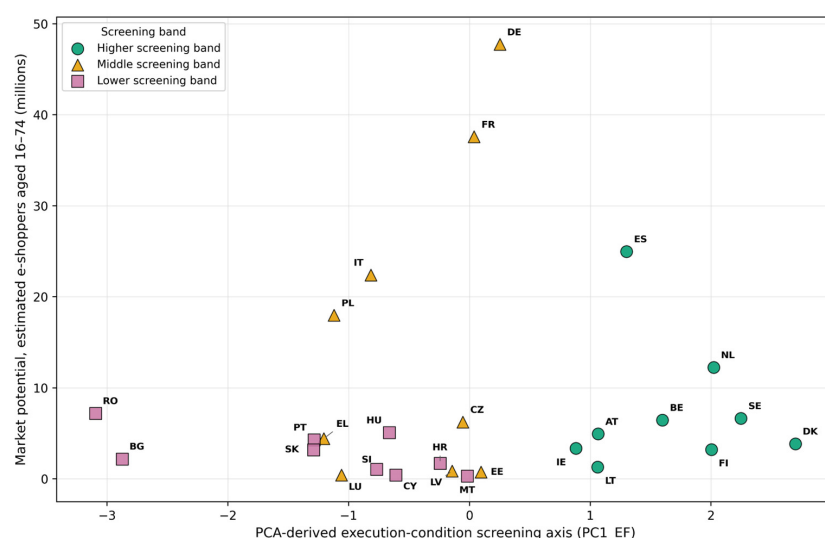


Figure 2. EU-27 CBEC screening portfolio. The horizontal axis shows PC1_EF, interpreted as the PCA-derived execution-condition screening axis, and the vertical axis shows market potential estimated using the population aged 16–74 and online-shopping incidence. Marker color and shape denote the rule-based screening band. CBO is reported in Table 2 as a separate demand-side overlay.

The screening bands should therefore be read together with the continuous portfolio. Spain and the Netherlands combine relatively high PC1_EF positions with substantial market potential, while Germany and France remain large-scale markets in the middle screening band under the baseline allocation. Smaller countries such as Denmark, Sweden, Finland, Austria, Lithuania and Ireland also occupy relatively high PC1_EF positions but differ substantially in market scale and cross-border buying openness.

Table 2. Country-level screening bands. Sorted by screening band and then by PC1_EF within band. MP is estimated using the population aged 16–74 and online-shopping incidence; CBO is retained as a separate demand-side overlay.

Country Code	Country	PC1_EF	MP 16–74 Estimated E-Shoppers	CBO (%)	Screening Band
DK	Denmark	2.698	3,851,440	39.88	Higher screening band
SE	Sweden	2.248	6,646,392	29.40	Higher screening band
NL	Netherlands	2.021	12,242,934	34.40	Higher screening band
FI	Finland	2.003	3,213,497	43.62	Higher screening band
BE	Belgium	1.598	6,454,643	62.41	Higher screening band
ES	Spain	1.301	24,966,203	31.51	Higher screening band
AT	Austria	1.064	4,933,836	69.21	Higher screening band
LT	Lithuania	1.061	1,303,679	36.72	Higher screening band
IE	Ireland	0.881	3,336,901	55.23	Higher screening band
DE	Germany	0.252	47,732,770	20.25	Middle screening band
EE	Estonia	0.094	730,873	42.98	Middle screening band
FR	France	0.038	37,581,530	38.66	Middle screening band
CZ	Czechia	−0.056	6,225,115	35.63	Middle screening band
LV	Latvia	−0.145	865,654	46.35	Middle screening band
IT	Italy	−0.816	22,390,584	37.69	Middle screening band
LU	Luxembourg	−1.060	403,145	69.50	Middle screening band
PL	Poland	−1.121	17,963,872	12.63	Middle screening band
EL	Greece	−1.205	4,426,274	27.80	Middle screening band
MT	Malta	−0.019	291,488	63.44	Lower screening band
HR	Croatia	−0.243	1,715,185	46.65	Lower screening band
CY	Cyprus	−0.611	409,549	80.75	Lower screening band
HU	Hungary	−0.664	5,089,662	42.38	Lower screening band
SI	Slovenia	−0.769	1,040,315	50.17	Lower screening band
PT	Portugal	−1.287	4,287,942	45.29	Lower screening band
SK	Slovakia	−1.291	3,184,246	39.02	Lower screening band
BG	Bulgaria	−2.876	2,183,539	27.40	Lower screening band
RO	Romania	−3.097	7,185,276	18.73	Lower screening band

Read together, the scatter plot (Figure 2), screening-band map (Figure 3), and country table (Table 2) provide complementary views of the same first-stage screening result: continuous country positions, geographic distribution and a compact rule-based band summary.

4.3. Enterprise-Side Criterion-Consistency Results

The enterprise-side check evaluates whether stronger positions on the PCA-derived execution-condition screening axis are associated with higher e-commerce turnover intensity at the enterprise level. On the usable 25-country sample, PC1_EF showed a positive Spearman rank association with ETI ($\rho = 0.4862$, $p = 0.014$). This is reported as a criterion-consistency diagnostic finding, not as a threshold-based validation result.

This observed association provides enterprise-side consistency evidence within the limits of the available official data. ETI is used because it is the closest available 2023 enterprise-side outcome signal in the public-data design, but its partial coverage and shared statistical context limit the strength of the inference.

The leave-one-out jackknife indicates that the observed positive association is not driven by a single country case. Appendix Figure A2 provides the country-level ETI scatter and the full leave-one-out results are reported in Appendix Table A2.

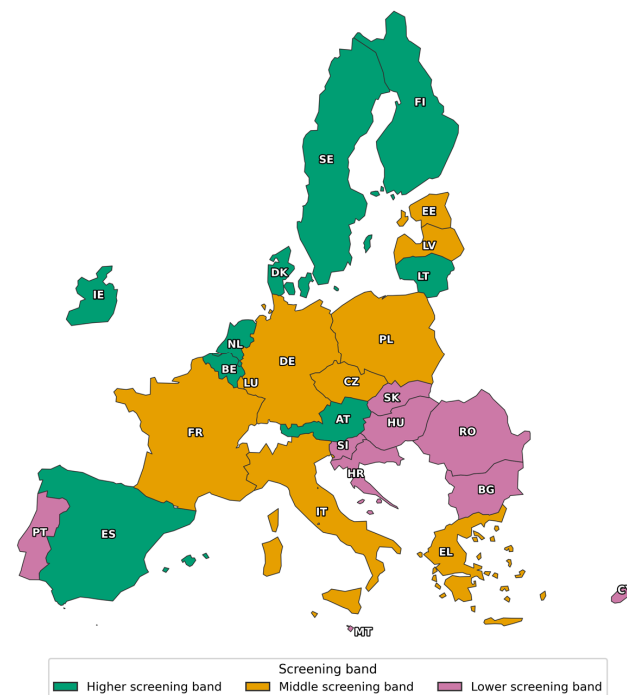


Figure 3. Geographic distribution of EU-27 screening bands. Countries are colored by the rule-based screening band derived from the baseline LPI gate and PC1_EF split procedure. The map provides a geographic view of the auxiliary first-stage screening summary; the continuous country positions are shown in Figure 2.

4.4. Diagnostic and Sensitivity Results

Table 3 provides a compact summary of the diagnostic and sensitivity checks; detailed supporting evidence is provided in Appendix Tables A1–A6.

Table 3. Compact diagnostic and sensitivity checks.

Check	N	Metric	Observed Value	<i>p</i> -Value	Diagnostic Finding
ETI criterion-consistency	25	Spearman ρ	0.4862	0.014	Positive criterion-consistency evidence
GDP_PPS prosperity association	27	Spearman ρ	0.6661	<0.001	Prosperity association reported
CBO overlay diagnostic	27	Spearman ρ	0.1374	0.494	Demand-side overlay check
LPI gate-family sensitivity	27	Maximum screening-band change share	0.1111	Not applicable	Gate-family sensitivity check
Equal-weight aggregation sensitivity	27	Spearman ρ vs. PC1_EF	0.9988	<0.001	Aggregation-rule sensitivity; max rank shift 1
No-DFP leave-one-variable-out	27	Spearman ρ vs. baseline PC1_EF	0.9451	Not applicable	DFP proxy sensitivity
No-LPI leave-one-variable-out	27	Spearman ρ vs. baseline PC1_EF	0.9194	Not applicable	LPI sensitivity
No-LPI/no-gate band sensitivity	27	Changed countries	PC1-only: 8; no-LPI: 11	Not applicable	Screening-band sensitivity

The GDP_PPS diagnostic shows a positive prosperity association with PC1_EF, but it is reported as interpretive context rather than as proof of conceptual independence from

prosperity. The rank-difference results show where the screening-axis order diverges from a simple GDP_PPS ordering. Figure A1 illustrates this divergence pattern graphically, and full country-level results are reported in Appendix Table A1.

The LPI gate-family sensitivity check shows limited changes in the baseline screening-band allocation across modest variations in the rank-aware gate fraction. Across the tested gate family, the maximum observed screening-band change share is 0.1111. Figure A3 presents the screening-band change share across the five tested gate fractions, and full gate-family results are reported in Appendix Table A3.

The no-LPI/no-gate sensitivity check provides a stricter view of the banding rule. It compares the baseline screening bands with PC1-only tertile bands and with tertile bands derived from a no-LPI backbone. This check shows that band membership is more sensitive than the continuous country positions. The continuous portfolio therefore remains the main empirical view. Detailed results are reported in Appendix Table A6.

The equal-weight comparison and leave-one-variable-out PCA checks further support the interpretation that the main screening order is not driven by a single aggregation choice or a single retained indicator. These checks are summarized in Table 3 and reported in detail in Appendix Table A5. They are used as sensitivity evidence, not as alternative model specifications for the main analysis.

The CBO overlay diagnostic shows no significant rank association with PC1_EF ($\rho = 0.1374$, $p = 0.494$). This finding is consistent with treating CBO as a behaviorally distinct demand-side overlay rather than as part of the PCA-derived axis.

Taken together, the results support a portfolio-first reading of the framework. PC1_EF summarizes execution conditions, while MP and CBO keep market scale and cross-border buying openness visible as separate dimensions of comparison.

5. Discussion

5.1. PC1_EF as a PCA-Derived Execution-Condition Screening Axis

PC1_EF explains 67.84% of the variance in the three-variable backbone, and all retained loadings are positive. The standardized backbone condition number is approximately 2.44, suggesting no severe collinearity among the inputs. The component is interpreted as a PCA-derived execution-condition screening axis defined by the three observed indicators. The diagnostics and sensitivity checks clarify the scope and limits of this interpretation.

This reading is consistent with the broader literature on country-level e-commerce development and enterprise digitalization. European e-commerce development is better understood as a combination of technological, institutional and organizational conditions than as the outcome of one driver alone [10,12,60]. Enterprise-side digital commerce also develops through adoption and routinization rather than as a simple binary condition [61]. The present screening axis is narrower than those broader frameworks, but it follows the same logic by summarizing a focused set of public-data signals relevant to first-stage CBEC comparison.

The composition of the screening axis also reflects the way cross-border e-commerce operates in practice. ESP captures the extent to which digital selling is embedded in national business structures. DFP serves as a country-level proxy for digital financial participation rather than enterprise payment infrastructure or institutional trust. LPI captures broad national logistics capability. Read together, these three signals provide a compact execution-condition axis for comparing EU-27 markets at the first screening stage. That interpretation is also consistent with EU cross-border e-commerce work emphasizing the continuing relevance of delivery, payment and institutional frictions, together with logistics capability, for cross-border transaction performance [3,38].

Denmark and Sweden occupy the upper end of PC1_EF, with relatively high values across all three retained inputs. Denmark records an ESP of 36.67%, a DFP of 96.22% and an LPI score of 4.1, while Sweden records 38.07%, 84.49% and 4.0, respectively. Romania and Bulgaria occupy the lower end, with lower ESP and DFP values and LPI scores of 3.2. These positions describe relative country profiles in the 2023 EU-27 cross-section; they are not estimates of market-entry outcomes.

5.2. Portfolio-First Interpretation and Country-Level Reading

Keeping execution conditions, market potential and cross-border buying openness separate produces interpretable country profiles. Figure 2 presents continuous positions together with market scale, while Table 2 and Figure 3 provide auxiliary band summaries. Spain and the Netherlands combine relatively high PC1_EF positions with above-median market potential. Germany and France remain prominent by scale but fall within the middle screening band under the baseline rule.

International market selection research treats foreign-market evaluation as a staged screening problem rather than as a single final ordering [18]. Related work also views market selection and segmentation as multidimensional assessments of attractiveness and fit [17,19], while more recent evidence shows that market, network and opportunity selection remain filtering problems rather than scoreboard exercises [16]. The present results illustrate this multidimensionality: market scale and PC1_EF do not necessarily produce the same ordering. The portfolio keeps execution conditions, scale and CBO visible before firm-, product- and channel-specific evaluation. It remains narrower than firm-level market-selection studies because it does not observe firm resources, market knowledge, channel choice or realized entry outcomes.

Online retail market-selection evidence points in the same direction. Schu and Morschett [63] showed that foreign market choice by online retailers depends on a bundle of country characteristics, including market size, rule of law, common language, local market knowledge and logistics performance. These determinants do not necessarily move together. The present results qualify a scale-only interpretation: larger markets do not always occupy the highest PC1_EF positions. The framework therefore organizes early market comparison rather than producing a definitive ranking or entry recommendation.

5.3. ETI as Enterprise-Side Criterion-Consistency Evidence

PC1_EF is positively associated with ETI in the 25-country sample ($\rho = 0.4862$, $p = 0.014$). The leave-one-out jackknife shows that no single country drives the association. Because ETI is unavailable for Luxembourg and Romania and overlaps conceptually with enterprise e-commerce activity, the result is interpreted as partial criterion-consistency evidence rather than external validation.

This reading is consistent with the enterprise-side literature discussed earlier. E-commerce turnover in Europe has been linked to institutional conditions such as consumer protection and cannot be reduced to macroeconomic prosperity alone [55]. Enterprise website functionality and digital commerce adoption also vary across EU countries and can be understood as staged capabilities rather than as simple binary conditions [61,62]. These studies support using ETI as an enterprise-side consistency signal, while keeping the interpretation focused on first-stage screening rather than prediction.

5.4. Prosperity Association and Rank-Difference Interpretation

The GDP_PPS diagnostic shows a positive association with PC1_EF ($\rho = 0.6661$, $p < 0.001$). It is used to examine prosperity association and rank differences; it does not imply that PC1_EF is independent of prosperity.

The rank-difference cases make this interpretation more concrete. Luxembourg remains the clearest divergence: it has the highest GDP_PPS position but a much lower PC1_EF rank. Spain, Lithuania and Latvia show the opposite pattern, ranking better on the screening axis than on GDP_PPS. These examples show why the screening axis should be read together with the prosperity diagnostic: it preserves information about enterprise e-sales, digital financial participation and logistics conditions that is not visible in a simple prosperity ordering.

Country-level e-commerce development studies have repeatedly shown that digital-commerce outcomes are shaped by institutional and digital conditions that do not reduce neatly to general wealth. Institutional conditions such as consumer protection have been linked to e-commerce turnover, while broad structural macroeconomic variables appear to have more limited explanatory power [55]. Country-level adoption research also shows that technological, institutional and cultural conditions matter for e-commerce development [10]. EU-27 panel evidence points in the same direction, since digital behavior and internet-banking-related variables help explain e-commerce development [11]. At the enterprise side, e-commerce functionalities vary across EU countries and are not simply aligned with general development levels [62].

5.5. Screening-Band Sensitivity Under the LPI Gate Family

The screening-band sensitivity analysis examines the retained rank-aware LPI gate and no-LPI/no-gate variants. Across the tested gate family, the maximum screening-band change share is 0.1111. The broad band pattern remains similar, although individual band membership is more sensitive than the continuous country positions.

Because LPI enters both the backbone and the rank-aware gate, the LPI gate-family and no-LPI/no-gate results are reported separately. They show how band membership changes when the gate is varied or removed and when LPI is excluded from the backbone.

Substantively, LPI remains relevant because logistics capability is central to cross-border e-commerce execution. Distance and delivery design still matter in online cross-border transactions, including in digitally mature settings [8]. Trade facilitation, customs procedures, logistics services and information systems are also part of cross-border e-commerce performance [38]. At country level, logistics performance remains connected to cross-border e-commerce trade, and LPI is best read here as a broad national logistics-capability signal rather than as a parcel-delivery measure [9,39]. Its dual role is retained transparently and examined through the sensitivity checks reported in Section 4 and Appendix A.

5.6. Managerial and Policy Implications

To illustrate how the framework may be used, consider a resource-constrained EU SME comparing the Netherlands, Germany and Denmark. Figure 2 shows that the Netherlands combines a relatively high PC1_EF position (2.021) with an estimated market potential of 12.24 million online shoppers. Germany has a much larger estimated market potential (47.73 million) but a more central PC1_EF position (0.252), while Denmark occupies the highest PC1_EF position (2.698) and has a smaller estimated market potential of 3.85 million. Table 2 reports CBO values of 34.40%, 20.25% and 39.88%, respectively. Band membership serves only as a compact auxiliary summary, not as an entry recommendation. By keeping execution conditions, market scale and cross-border buying openness separate, the comparison can help the SME form an initial shortlist. A final decision would still require product-, firm- and channel-specific evidence on demand, competition, regulation, payments, fulfillment, returns and the firm's own resources.

For SMEs, the framework can support an initial shortlist and show what information is still needed before entry. Export-promotion agencies can use the country profiles to organize market intelligence and identify dimensions that merit closer examination, without treating the bands as a country league table. Digital-platform operators can use the portfolio to identify markets where seller onboarding, payment options, fulfillment and local support merit closer study. Platform-level decisions would still require direct evidence on payment infrastructure and seller services.

For logistics providers, the profiles can indicate where separate parcel-level analysis of delivery, fulfillment and returns is needed because LPI is a broad national logistics measure rather than a last-mile metric. Policymakers can use the framework to organize comparative evidence on enterprise digital selling, digital financial participation, logistics capability and cross-border buying openness. These comparisons are intended to identify areas for further investigation rather than to serve as a policy scorecard or market recommendation.

5.7. Limitations and Future Research

Several limitations shape the interpretation of the results. The framework is country-level and based on public data, so it does not replace firm-, product- or channel-level market-entry analysis. The design is cross-sectional and anchored in the 2023 data vintage; it should not be interpreted causally or dynamically. ESP captures enterprise e-sales penetration but does not isolate cross-border B2C e-commerce. DFP is an internet-banking-based proxy for digital financial participation, not a direct measure of enterprise payment readiness, gateway integration, checkout architecture or institutional trust.

MP uses an age-consistent population aged 16–74 denominator, but it remains a scale proxy based on population and online-shopping incidence rather than purchasing power, category demand or actual cross-border spending. ETI is a partial enterprise-side criterion-consistency check for 25 countries; Luxembourg and Romania are unavailable, and the measure overlaps conceptually with enterprise e-commerce activity. GDP_PPS remains a prosperity-association and rank-difference diagnostic. LPI also has a dual role because it enters the PCA backbone and the rank-aware gate. The sensitivity checks improve transparency, but the proxy and banding choices remain limitations.

The screening bands should therefore be read only as compact auxiliary summaries of the continuous portfolio. They can help organize first-stage comparison, but the continuous country positions in Figure 2 remain the primary basis for interpreting differences among markets.

Future research can extend the framework through repeated cross-sections or longitudinal vintages, provided temporal coherence is maintained. Comparable non-EU applications would require harmonized definitions. Firm-level or product-category outcomes, consumer expenditure, category demand and more specific payment and parcel-level logistics indicators could support stronger empirical assessment of the framework's practical relevance. Alternative weighting approaches may become useful if the indicator set and decision context expand. Machine-learning methods would require substantially larger longitudinal or firm-level data, a defined external outcome and out-of-sample evaluation; they are not appropriate for the current 27-country cross-section.

6. Conclusions

This study developed a 2023 public-data screening framework for EU-27 cross-border e-commerce market-entry assessment. Its central contribution is a portfolio-first structure that separates execution conditions, market potential and cross-border buying openness instead of compressing them into a single country score. Market potential is measured with an age-consistent population aged 16–74 denominator, while CBO remains a separate

demand-side overlay. EU markets differ across these dimensions in ways that would be obscured by market size alone or by a generic readiness score.

Empirically, the retained backbone produced an interpretable first component, PC1_EF. It explained 67.84% of the variance in enterprise e-sales penetration, digital financial participation and logistics capability. All three loadings were positive, and the standardized backbone condition number indicated no severe collinearity among the three retained inputs. The resulting component is best read as a PCA-derived execution-condition screening axis for comparing EU-27 country positions in 2023.

The portfolio view clarifies the value of keeping scale, execution conditions and demand-side openness visible at the same time. Countries can be large without occupying the highest positions on the screening axis, while smaller countries can occupy higher PC1_EF positions despite more limited market scale. The weak and non-significant association between cross-border buying openness and PC1_EF further supports treating openness as a separate behavioral overlay rather than as part of the retained backbone.

The diagnostic and sensitivity checks help place this structure in context. PC1_EF shows positive criterion-consistency evidence with enterprise-side e-commerce turnover intensity in the usable 25-country sample, and the leave-one-out jackknife indicates that the association is not driven by a single country. GDP_PPS is used as a prosperity-association and rank-difference diagnostic, showing that the screening axis should be interpreted alongside national prosperity patterns. The LPI gate-family and no-LPI/no-gate checks clarify the sensitivity and limits of the rule-based band summaries. The equal-weight and leave-one-variable-out checks assess the sensitivity of the continuous country order, which remains the primary basis for interpretation.

Overall, the framework offers a transparent and reproducible basis for initial EU-27 market comparison while keeping execution conditions, market scale and cross-border openness separate. For practitioners, it can support an initial market shortlist, but product-, firm- and channel-specific analysis remains necessary before entry. Future research can extend the approach through cleaner full-sample enterprise-side outcome data, multiple data vintages and sector- or firm-specific adaptations of the portfolio.

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Institutional Review Board Statement: Not applicable.

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Data Availability Statement: The data and code that support the findings of this study are openly available at <https://github.com/calinadriancomes/EU27-CBEC-Market-Entry-Screening> (accessed on 30 April 2026). The repository contains the 2023 EU-27 public-data package, processed analytical files, notebooks, scripts, generated figures and documentation required to reproduce the portfolio-first cross-border e-commerce market-entry screening workflow. The analytical dataset was derived from public Eurostat resources and the World Bank Logistics Performance Index 2023.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

B2B	Business-to-business
B2C	Business-to-consumer
CBEC	Cross-border e-commerce
CBO	Cross-border buying openness
DESI	Digital Economy and Society Index
DFP	Digital financial participation proxy
ESP	Enterprise e-sales penetration
ETI	E-commerce turnover intensity
EU-27	The 27 member states of the European Union
GDP	Gross domestic product
GDP_PPS	GDP per capita in purchasing power standards
ICT	Information and communication technology
JRC	Joint Research Centre
LPI	Logistics Performance Index
KMO	Kaiser–Meyer–Olkin measure of sampling adequacy
MP	Market potential
OECD	Organisation for Economic Co-operation and Development
PCA	Principal component analysis
PC1	First principal component
PC1_EF	PCA-derived execution-condition screening axis
PC_ETURN	Eurostat fallback extraction unit used in the ETI workflow
PC_TURN	Eurostat primary extraction unit used in the ETI workflow
PPS	Purchasing power standards
UNCTAD	United Nations Conference on Trade and Development

Appendix A

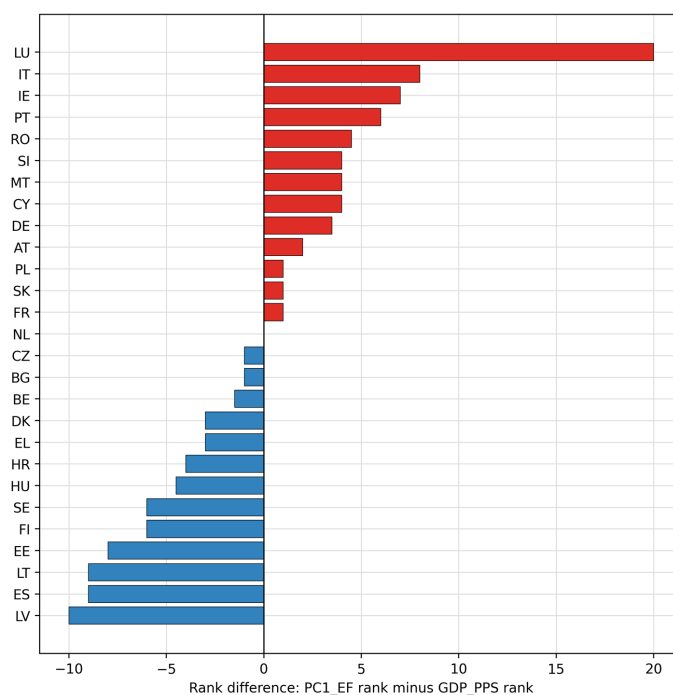


Figure A1. Difference between PC1_EF rank and GDP_PPS rank across the EU-27. Negative values (blue bars) indicate a better PC1_EF rank than GDP_PPS rank; positive values (red bars) indicate a better GDP_PPS rank than PC1_EF rank.

Table A1. Country-level PC1_EF and GDP_PPS rank differences.

Country Code	Country	PC1_EF Rank	GDP_PPS Rank	PC1_EF Rank Minus GDP_PPS Rank	GDP_PPS Index
LU	Luxembourg	21	1	20	248
IT	Italy	20	12	8	98
IE	Ireland	9	2	7	218
PT	Portugal	24	18	6	81
RO	Romania	27	22.5	4.5	75
SI	Slovenia	19	15	4	91
MT	Malta	13	9	4	109
CY	Cyprus	17	13	4	97
DE	Germany	10	6.5	3.5	118
AT	Austria	7	5	2	121
FR	France	12	11	1	99
SK	Slovakia	25	24	1	74
PL	Poland	22	21	1	77
NL	Netherlands	3	3	0	131
CZ	Czechia	14	15	−1	91
BG	Bulgaria	26	27	−1	63
BE	Belgium	5	6.5	−1.5	118
DK	Denmark	1	4	−3	126
EL	Greece	23	26	−3	68
HR	Croatia	16	20	−4	78
HU	Hungary	18	22.5	−4.5	75
FI	Finland	4	10	−6	103
SE	Sweden	2	8	−6	111
EE	Estonia	11	19	−8	80
ES	Spain	6	15	−9	91
LT	Lithuania	8	17	−9	86
LV	Latvia	15	25	−10	70

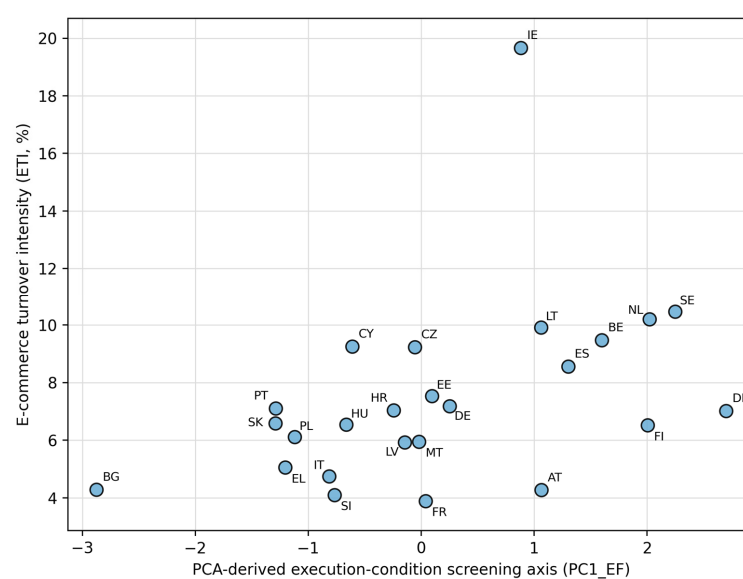
**Figure A2.** ETI criterion-consistency scatter for the usable 25-country sample. The figure plots PC1_EF against enterprise e-commerce turnover intensity.

Table A2. Leave-one-out ETI criterion-consistency results.

Excluded Country	Spearman ρ	p -Value
AT	0.576	0.003
BE	0.449	0.028
BG	0.451	0.027
CY	0.511	0.011
CZ	0.497	0.014
DE	0.469	0.021
DK	0.517	0.010
EE	0.469	0.021
EL	0.468	0.021
ES	0.465	0.022
FI	0.528	0.008
FR	0.523	0.009
HR	0.497	0.014
HU	0.483	0.017
IE	0.477	0.019
IT	0.470	0.020
LT	0.467	0.021
LV	0.486	0.016
MT	0.496	0.014
NL	0.436	0.033
PL	0.480	0.018
PT	0.524	0.009
SE	0.436	0.033
SI	0.464	0.022
SK	0.499	0.013

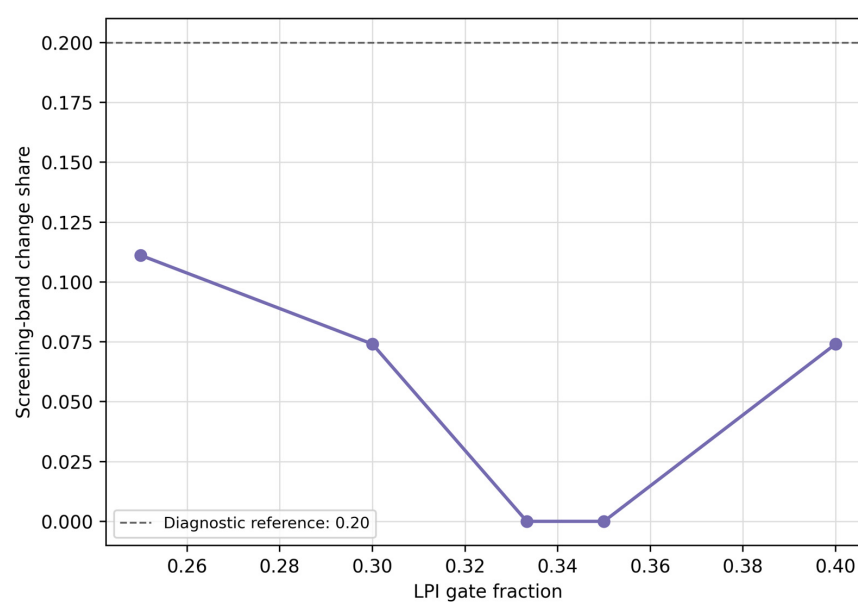
**Figure A3.** Screening-band change share across the tested LPI gate family. The baseline gate is one-third.

Table A3. LPI gate-family screening-band sensitivity results.

LPI Gate Fraction	Changed Countries Count	Change Share	Changed Countries
0.25	3	0.1111	DE, HR, HU
0.30	2	0.0741	DE, HR
0.333	0	0	None
0.35	0	0	None
0.40	2	0.0741	CZ, IE

Table A4. PCA input correlations, KMO and Bartlett diagnostics.

Panel A. Pearson correlation matrix.			
Variable	ESP	DFP	LPI
ESP	1.000	0.644	0.400
DFP	0.644	1.000	0.498
LPI	0.400	0.498	1.000
Panel B. KMO and Bartlett diagnostics.			
Diagnostic		Value	
KMO		0.6491	
Bartlett chi-square		20.2033	
Bartlett df		3	
Bartlett <i>p</i> -value		0.000154	

Table A5. Aggregation-rule and leave-one-variable-out sensitivity checks.

Check	Statistic/Value	Additional Information	Role in Analysis
Equal-weight Spearman ρ vs. PC1_EF	0.9988	Max absolute rank shift = 1	Aggregation-rule sensitivity
Equal-weight Pearson r vs. PC1_EF	0.9994	—	Aggregation-rule sensitivity
Drop ESP Spearman ρ vs. baseline PC1_EF	0.9267	Kept variables: DFP, LPI; max rank shift = 7; mean rank shift = 2.22	Leave-one-variable-out sensitivity
Drop DFP Spearman ρ vs. baseline PC1_EF	0.9451	Kept variables: ESP, LPI; max rank shift = 6; mean rank shift = 1.78	DFP proxy sensitivity
Drop LPI Spearman ρ vs. baseline PC1_EF	0.9194	Kept variables: ESP, DFP; max rank shift = 9; mean rank shift = 2.37	LPI and dual-use sensitivity

Table A6. No-LPI and no-gate screening-band sensitivity.

Country Code	Country	Baseline Screening Band	PC1-Only Band	Changed vs. PC1-Only	No-LPI Band	Changed vs. No-LPI
DK	Denmark	Higher screening band	Higher screening band	No	Higher screening band	No
SE	Sweden	Higher screening band	Higher screening band	No	Higher screening band	No
NL	Netherlands	Higher screening band	Higher screening band	No	Higher screening band	No
FI	Finland	Higher screening band	Higher screening band	No	Higher screening band	No
BE	Belgium	Higher screening band	Higher screening band	No	Higher screening band	No
ES	Spain	Higher screening band	Higher screening band	No	Higher screening band	No
AT	Austria	Higher screening band	Higher screening band	No	Middle screening band	Yes
LT	Lithuania	Higher screening band	Higher screening band	No	Higher screening band	No
IE	Ireland	Higher screening band	Higher screening band	No	Higher screening band	No
MT	Malta	Lower screening band	Middle screening band	Yes	Higher screening band	Yes
HR	Croatia	Lower screening band	Middle screening band	Yes	Middle screening band	Yes
CY	Cyprus	Lower screening band	Middle screening band	Yes	Middle screening band	Yes

Table A6. Cont.

Country Code	Country	Baseline Screening Band	PC1-Only Band	Changed vs. PC1-Only	No-LPI Band	Changed vs. No-LPI
HU	Hungary	Lower screening band	Middle screening band	Yes	Middle screening band	Yes
SI	Slovenia	Lower screening band	Lower screening band	No	Middle screening band	Yes
PT	Portugal	Lower screening band	Lower screening band	No	Lower screening band	No
SK	Slovakia	Lower screening band	Lower screening band	No	Lower screening band	No
BG	Bulgaria	Lower screening band	Lower screening band	No	Lower screening band	No
RO	Romania	Lower screening band	Lower screening band	No	Lower screening band	No
DE	Germany	Middle screening band	Middle screening band	No	Lower screening band	Yes
EE	Estonia	Middle screening band	Middle screening band	No	Middle screening band	No
FR	France	Middle screening band	Middle screening band	No	Middle screening band	No
CZ	Czechia	Middle screening band	Middle screening band	No	Middle screening band	No
LV	Latvia	Middle screening band	Middle screening band	No	Middle screening band	No
IT	Italy	Middle screening band	Lower screening band	Yes	Lower screening band	Yes
LU	Luxembourg	Middle screening band	Lower screening band	Yes	Lower screening band	Yes
PL	Poland	Middle screening band	Lower screening band	Yes	Lower screening band	Yes
EL	Greece	Middle screening band	Lower screening band	Yes	Lower screening band	Yes

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