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DIGITAL CONNECTIVITY AND ICT SERVICE EXPORTS ACROSS ECONOMIES: AN EMPIRICAL INVESTIGATION USING INTERNATIONAL PANEL DATA

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Abstract:

This analysis examines whether distinct dimensions of digital connectivity are associated with ICT service export specialization across economies. Using World Bank data, it constructs an unbalanced panel of 2,397 observations across 187 economies from 2010 to 2024 and estimates regressions with economy and year effects and clustered standard errors. Ten additional fixed broadband subscriptions per 100 people are associated with a 2.045 percentage point increase in the ICT share of service exports, with a 95% confidence interval from 0.658 to 3.431 percentage points. This positive association persists under alternative clustering, balanced panel restrictions and a shorter observation period. Internet use is sensitive to sample coverage, while mobile subscription intensity shows no clear association at the 5% level. The findings distinguish infrastructure penetration from broader digital participation without identifying causal transmission mechanisms. The contribution refines information cost explanations by separating connectivity expansion from export specialization. Policymakers and managers should assess connectivity dimensions individually rather than interpret rising connection totals as equivalent evidence of digital export readiness.

Key Words: Digital Connectivity; ICT Service Exports; Export Specialization; Broadband Penetration; Panel Regression.

1. Introduction:

Expanding digital connectivity does not necessarily translate into greater specialization in information and communication technology service exports. Internet access can facilitate transactions throughout an economy, supporting ICT services alongside tourism, finance and other internationally traded activities. Consequently, connectivity may accompany export expansion without increasing the ICT share of service exports. This distinction matters for governments assessing digital development strategies: rising internet use or subscription totals cannot, by themselves, establish progress toward ICT export specialization. The substantive question concerns which dimensions of connectivity are associated with the composition of service exports. Information frictions provide a theoretical basis for examining this relationship. Firms incur costs when identifying customers, evaluating suppliers and coordinating transactions across borders. Allen, 2014, demonstrates how imperfect information shapes trading patterns, while Goldfarb and Tucker, 2019, explain how digital technologies reduce several economic costs, including search and verification. These mechanisms suggest that connectivity can support international exchange, but they do not imply an identical response across sectors. Changes in export composition depend on whether ICT services expand relative to other service activities. The theoretical expectation therefore concerns differentiated relationships between connectivity dimensions and export specialization rather than a uniform digitalization effect.

The distinction between connectivity measures is central to this argument. Internet use captures participation in digital communication across the population. Fixed broadband subscriptions measure the density of fixed connections, while mobile cellular subscriptions measure mobile connection intensity. These indicators describe related aspects of communication systems but are not interchangeable. Population internet use includes activities unrelated to international production, fixed broadband density does not directly measure connection quality, and cellular subscriptions do not identify unique users or mobile broadband use. Combining them into a single measure would obscure differences that are relevant to interpreting export specialization. Existing research establishes that digital communication can influence trade, although its findings concern different outcomes and analytical scales. Choi, 2010, identifies a positive relationship between internet use and service trade. Fernandes and colleagues, 2019, show that internet expansion supported manufacturing exports among Chinese firms. Malgouyres, Mayer and Mazet Sonilhac, 2021, identify increased firm imports following broadband expansion in France. These contributions establish the relevance of connectivity to international exchange, but service trade, manufacturing exports and firm imports do not measure the relative importance of ICT services within service exports. Their findings therefore leave open whether different connectivity dimensions exhibit distinct associations with ICT export composition.

Technological complementarity further qualifies the expectation that additional connections translate directly into productive specialization. Akerman, Gaarder and Mogstad, 2015, demonstrate that broadband adoption changes the relative productivity of different tasks and complements skilled work. Hjort and Poulsen, 2019, identify employment responses to faster internet in African economies, with firm evidence indicating contributions from entry, productivity and exporting. Together, these findings explain why communication infrastructure can support productive activity without generating uniform outcomes. They motivate distinguishing observed connectivity indicators while avoiding claims that aggregate subscription measures directly identify the organizational processes behind export performance. The outcome examined here is ICT service exports as a percentage of total service exports. This measure captures relative export specialization rather than export scale, productivity or growth. An increasing share indicates that ICT services account for a larger proportion of service export receipts, but it does not establish that their absolute value has increased. Conversely, ICT exports can expand while their share falls if other service exports expand faster. The measurement choice consequently addresses a question distinct from whether connectivity increases trade

volumes. It allows an examination of the relationship between communication penetration and the sectoral composition of internationally traded services.

The reviewed evidence does not establish whether population internet use, fixed broadband penetration and mobile subscription intensity retain distinct associations with ICT service export shares when evaluated simultaneously within an international panel. Addressing this question requires separating persistent differences between economies from changes over time and distinguishing pooled correlations from adjusted relationships. It also requires examining whether conclusions depend on continuous indicator availability. The contribution is therefore bounded and empirical: the analysis differentiates connectivity dimensions against a common export composition measure and assesses the stability of those relationships across implemented sample and inference choices. This study aims to examine how internet use, fixed broadband subscriptions and mobile cellular subscriptions are associated with ICT service exports as a share of total service exports. The research question asks whether these connectivity dimensions display distinct conditional relationships with ICT export specialization across economies. The specific objectives are to estimate the association for each dimension while retaining the other two, and to assess how the resulting conclusions change with sample coverage, observation period and clustering assumptions. These objectives concern observed associations rather than causal effects.

The analysis uses an unbalanced annual panel containing 2,397 complete observations across 187 economies from 2010 to 2024. World Bank World Development Indicators provide the four substantive measures. The baseline regression includes economy and year effects, permitting an examination of changes within economies after accounting for common annual influences. Standard errors are clustered by economy. Exploratory sensitivity checks apply clustering by both economy and year, restrict the sample to continuously observed economies and examine the period from 2010 to 2019. This design supports comparisons across connectivity dimensions using a common analytical sample while retaining the inferential limits of observational data. The findings identify fixed broadband penetration as the most consistent connectivity correlate of ICT export specialization across the implemented specifications. Internet use is sensitive to the inclusion of continuously observed economies, while mobile subscription intensity does not display a clear association at the 5% significance level. These results refine the application of information cost explanations by showing that broader digital participation and greater ICT export specialization need not move together. Their practical relevance lies in distinguishing connection indicators when evaluating digital export strategies. They do not establish investment returns or imply that subscription expansion alone produces structural transformation.

2. Theory, Conceptual Framework and Research Questions Development:

Digital connectivity can reshape international specialization by reducing the costs of finding customers, exchanging information and coordinating production across borders. The theoretical foundation of this analysis combines information frictions with technological complementarity. Connectivity expands trading opportunities, but its economic value depends on whether firms can convert communication access into productive activity. Goldfarb and Tucker, 2019, identify reductions in search, replication, transportation, tracking and verification costs as central mechanisms of digital economic activity. This perspective connects national communication networks with the organizational decisions through which firms participate in international service markets. This analysis examines these relationships through an annual panel covering 2010 to 2024. Digital connectivity is represented by three observed measures: internet users as a percentage of the population, fixed broadband subscriptions per 100 people and mobile cellular subscriptions per 100 people. The outcome is ICT service exports as a percentage of total service exports. These measures distinguish population use, fixed network penetration and mobile subscription intensity. They are examined separately rather than combined into a latent construct or composite index. Because the outcome measures export composition, connectivity can accompany expanding ICT exports without increasing their share when other service exports expand faster. The framework therefore develops research questions without imposing a common direction across the three relationships.

Internet use measures the breadth of participation in digital communication. Wider use can enlarge the pool of customers, workers and suppliers accessible through digital channels. For service providers, this can reduce information asymmetry and facilitate communication before and after a transaction. The relevant mechanism is participation: infrastructure creates an opportunity to connect, whereas actual use indicates that people engage with that opportunity. Greater participation may support ICT service exports by improving customer discovery and coordination across locations. However, population internet use also includes activities unrelated to export production. Its association with ICT export specialization consequently depends on how use translates into commercial participation. Choi, 2010, reports a positive relationship between internet use and service trade. That finding supports the relevance of the proposed relationship but concerns service trade rather than the ICT share of service exports. It therefore does not establish the direction of the relationship examined here. Evidence from online markets strengthens the information cost mechanism. Lendle and colleagues, 2016, find that geographic distance constrains international transactions less strongly on eBay than in conventional trade, linking this difference to lower search costs and seller reputation mechanisms. Their evidence concerns goods traded through a platform, so its contribution here is theoretical rather than a direct prediction about ICT service export shares. The resulting question concerns whether broader internet participation corresponds to a different composition of service exports.

RQ1: How is internet use associated with ICT service exports as a percentage of total service exports, conditional on fixed broadband subscriptions, mobile cellular subscriptions, economy effects and year effects?

Fixed broadband subscriptions represent a different dimension of connectivity. Whereas internet use captures participation, fixed broadband penetration captures the prevalence of fixed access connections. Such connections can support sustained communication and the exchange of digital files required for remotely delivered services. Subscription density nevertheless measures neither connection speed nor service reliability. This analysis therefore treats it as an observed access measure rather than a direct measure of network quality. The theoretical link rests on complementarities between connectivity and productive capabilities. Firms can benefit from fixed access when their tasks require frequent information exchange and when workers can incorporate digital tools into production. Akerman, Gaarder and Mogstad, 2015, demonstrate that broadband adoption

complements skilled work and changes the relative productivity of different tasks. Their evidence implies that additional connections do not generate uniform economic responses. The same expansion in access can support different patterns of specialization across economies. Evidence on faster internet also identifies productive channels through firm activity. Hjort and Poulsen, 2019, link the arrival of fast internet in African economies to employment gains, with firm evidence indicating contributions from entry, productivity and exporting. These findings support the plausibility of a connection between communication infrastructure and internationally oriented production. They do not establish that fixed subscription density raises the ICT share of service exports. That distinction motivates a separate assessment of fixed broadband penetration.

RQ2: How are fixed broadband subscriptions associated with ICT service exports as a percentage of total service exports, conditional on internet use, mobile cellular subscriptions, economy effects and year effects?

Mobile cellular subscriptions capture the intensity of mobile connections relative to population. Mobile communication can reduce the cost of contacting customers, coordinating workers and obtaining market information. These behavioral changes can connect individual communication decisions with aggregate trading activity. Aker and Mbiti, 2010, document how mobile telephony reduces communication costs and improves market coordination in particular economic settings. Their synthesis also emphasizes that broader development benefits depend on complementary conditions. Mobile subscription intensity differs from both internet participation and fixed broadband penetration. Subscriptions can support voice communication without providing the capabilities required for delivering ICT services. Multiple subscriptions held by one person also mean that subscription density does not measure the proportion of connected individuals. Consequently, an increase in subscriptions cannot automatically be interpreted as an equivalent increase in productive digital participation. Mobile communication may facilitate ICT service provision, but it can also support other service activities that enter the denominator of the export share. These competing channels prevent a defensible directional prediction from the available measure alone. The framework therefore examines whether mobile subscription intensity has a distinct association with ICT export composition after accounting for the other connectivity dimensions.

RQ3: How are mobile cellular subscriptions associated with ICT service exports as a percentage of total service exports, conditional on internet use, fixed broadband subscriptions, economy effects and year effects?

The conceptual framework links each observed connectivity measure directly to the observed ICT service export share. These links represent conditional associations rather than causal effects or tested transmission mechanisms. Economy and year identifiers permit the analysis to account for persistent differences between economies and common annual influences. The three questions can be examined using the available complete observations, with each relationship assessed while retaining the other connectivity measures. This structure permits positive, negative, negligible or statistically inconclusive associations without changing the conceptual argument after examining the findings.

3. Data:

This analysis uses annual economy level observations to examine how digital connectivity relates to the composition of service exports. Data provenance, sample construction, measurement and estimation are documented to make the analysis traceable and reproducible.

3.1 Data Sources, Population, and Sample Construction:

The data originate from the World Bank World Development Indicators database, source identifier 2. The connectivity indicators draw on International Telecommunication Union statistics, while ICT service exports draw on International Monetary Fund balance of payments statistics. The database provides an established framework for organizing internationally comparable development indicators, as documented by the World Bank, 2014. The observations were retrieved through the public Indicators API and are available under Creative Commons Attribution 4.0. The workbook records the extraction and database update timestamps separately from the observation period. The extract contains revised historical observations rather than a frozen release contemporaneous with each observation year. The unit of analysis is an economy observed in a calendar year. The empirical setting covers international service exports and national digital connectivity from 2010 to 2024. ICT service exports represent an annual flow expressed as a share of total service exports. Internet use represents population participation in internet activity, while fixed broadband and mobile cellular subscriptions represent connection densities. These indicators retain their published annual reference periods without conversion into common period averages or growth rates.

The target population comprises economies participating in international service trade during the observation period. The accessible frame contains 217 World Bank economies and 3,255 possible annual observations. Regional, income and other aggregate entities were excluded using the World Bank economy classification. Selection followed data availability rather than statistical significance. An observation entered the analytical sample only when all four substantive indicators were available. Table 1 reports the sample construction. Missingness exclusions are sequential and mutually exclusive in this table. Their order provides an accounting of losses and does not imply an analytical ranking of the indicators.

Table 1: Sample construction

Stage	Economies Retained	Observations Retained	Observations Excluded At Stage	Inclusion or Exclusion Rule
Initial economy frame	217	3,255	0	Individual economies across 15 calendar years
Internet availability screen	209	2,894	361	Exclude observations without internet use
Fixed broadband availability screen	208	2,738	156	Exclude additional observations without fixed broadband subscriptions
Mobile availability screen	206	2,723	15	Exclude additional observations without mobile cellular subscriptions

Stage	Economies Retained	Observations Retained	Observations Excluded At Stage	Inclusion or Exclusion Rule
ICT export availability screen	187	2,397	326	Exclude additional observations without ICT service export shares
Verified analytical sample	187	2,397	0	Retain complete observations with unique economy and year identifiers
Baseline regression sample	187	2,397	0	All analytical observations retained by the estimator

The resulting panel is unbalanced. Each retained economy contributes between one and 15 observations, with a median of 15. Complete coverage is available for 101 economies. Annual analytical coverage ranges from 127 economies in 2024 to 170 in 2015. Thirty economies contribute no complete observations. The sample therefore represents the accessible population with joint indicator coverage rather than a random sample of all economies.

3.2 Data Integration, Cleaning, and Quality Assurance:

The four indicators were integrated using the World Bank economy identifier and calendar year. Economy names serve as descriptive labels rather than merge keys. Each indicator contributes at most one value to an economy and year combination. The integrated frame contains no duplicate keys, and its size remains equal to the expected 3,255 observations. The analytical worksheet matches the complete observations in the raw panel exactly. All indicators retain their published annual frequency. No frequency conversion, exchange rate conversion, inflation adjustment or temporal interpolation was applied. These operations are unnecessary because the analytical measures are percentages or subscriptions per 100 people. The historical extract incorporates revisions available when retrieved. It does not support claims about information available to decision makers at earlier observation dates. Table 2 distinguishes variable specific missingness from the sequential exclusions in Table 1. Missing values overlap across indicators, so the column totals cannot be added to obtain the number of excluded observations.

Table 2: Indicator availability in the initial frame

Indicator	Available Observations	Missing Observations	Missing Share
Internet use	2,894	361	11.09%
Fixed broadband subscriptions	2,900	355	10.91%
Mobile cellular subscriptions	2,984	271	8.33%
ICT service export share	2,643	612	18.80%

At least one indicator is missing in 858 observations across 116 economies. Missingness varies over time. In 2024, internet use is unavailable for 35 economies, fixed broadband and mobile subscriptions for 66 economies each, and ICT service export shares for 55 economies. The source extract does not distinguish every reporting gap from structural nonavailability. These entries remain missing rather than being assigned an unsupported substantive interpretation. The analytical sample uses complete observation deletion. No missing value was replaced with zero, and no imputation, interpolation or extrapolation was performed. This procedure preserves published values but excludes 26.36% of the initial observations. As Hughes and colleagues, 2019, explain, the implications of complete observation analysis depend on the missingness process. The availability screen therefore does not establish that retained and excluded observations are interchangeable. Quality checks examined key uniqueness, year coverage, numeric completeness and admissible ranges. Available internet percentages and ICT export shares remain between zero and 100, while subscription densities are nonnegative. Mobile subscriptions above 100 were retained because subscriptions are connections rather than unique individuals. No observations were trimmed or winsorized. Following the distinction emphasized by Aguinis, Gottfredson and Joo, 2013, an extreme published value was not treated as a data error solely because it differed from most observations. These checks establish internal consistency without constituting an independent audit of the original reporting systems.

3.3 Variable Measurement, Construction, and Validation:

The analysis represents digital connectivity through three observed indicators rather than an estimated index. Internet use captures participation, fixed broadband subscriptions capture fixed connection density, and mobile cellular subscriptions capture mobile connection intensity. ICT service exports measure the share of service export receipts attributed to information and communication technology services. The source definition includes computer, communication and information services. The outcome consequently measures export composition rather than export value or export growth. Table 3 provides the variable dictionary. Each substantive indicator enters the analysis in its published scale, without logarithmic transformation, standardization or aggregation.

Table 3: Variable dictionary

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
Internet use	Connectivity predictor	Published share of individuals using the internet	World Bank WDI, ITU	Percentage of population; annual	Untransformed; higher values indicate broader use	Exclude incomplete observations from joint analysis	2,894 available observations; does not measure commercial use or digital skills
Fixed broadband subscriptions	Connectivity predictor	Published fixed broadband subscriptions relative to population	World Bank WDI, ITU	Subscriptions per 100 people; annual	Untransformed; higher values indicate greater fixed connection density	Exclude incomplete observations from joint analysis	2,900 available observations; does not directly measure speed, reliability or affordability
Mobile cellular	Connectivity	Published mobile	World Bank	Subscriptions	Untransformed; higher	Exclude	2,984 available

Variable or Indicator	Analytical Role	Definition and Construction	Source and Identifier	Unit and Frequency	Transformation and Direction	Missing Value Rule	Coverage and Limitation
subscriptions	predictor	cellular subscriptions relative to population	WDI, ITU	per 100 people; annual	values indicate greater subscription intensity	incomplete observations from joint analysis	observations; includes multiple subscriptions and does not measure mobile broadband use
ICT service export share	Outcome	Published ICT service exports divided by total service exports and expressed as a percentage	World Bank WDI, IMF	Percentage of service exports; annual	Untransformed; higher values indicate greater ICT specialization within service exports	Exclude incomplete observations from joint analysis	2,643 available observations; changes can reflect movements in either numerator or denominator
Economy identifier	Panel key and fixed effect identifier	World Bank economy code	World Bank economy metadata	Identifier	Categorical	No missing identifiers retained	Identifies economies rather than firms
Calendar year	Time identifier and fixed effect identifier	Published reference year	World Bank indicator records	Annual identifier	Categorical	Restrict to 2010 to 2024	Does not provide within year timing

Table 4 reports descriptive statistics on the common analytical sample. Standard deviations use the sample denominator. All four indicators have identical analytical counts because the same completeness rule applies throughout.

Table 4: Descriptive statistics for the analytical sample

Indicator	Valid Observations	Mean	Standard Deviation	Median	Minimum	Maximum
Internet use	2,397	54.89	29.66	59.50	0.72	100.00
Fixed broadband subscriptions	2,397	14.33	14.08	9.80	0.00	63.08
Mobile cellular subscriptions	2,397	110.15	40.91	112.12	7.57	574.15
ICT service export share	2,397	9.01	9.99	5.74	0.003	63.35

The difference between the mean and median ICT export shares indicates an asymmetric distribution. Mobile subscriptions also contain substantial upper tail variation. These characteristics are retained in the original scales. A one-unit change in internet use or the export share denotes one percentage point, while a one-unit change in either subscription indicator denotes one additional subscription per 100 people.

3.4 Analytical Framework, Identification, and Reproducibility:

The analytical framework is associational. It examines whether changes in the three connectivity measures correspond to changes in ICT service export composition within economies after accounting for common annual influences. The baseline was estimated by ordinary least squares with economy and year indicators. All explanatory variables enter contemporaneously. The distinction between variation within economies and persistent differences between economies follows the panel interpretation discussed by Bell, Fairbrother and Jones, 2019. Equation 1 specifies the implemented baseline.

$$Y_{it} = \alpha_i + \lambda_t + \beta_1 I_{it} + \beta_2 B_{it} + \beta_3 M_{it} + \varepsilon_{it}$$

Here, Y_{it} denotes the ICT service export share for economy i in year t. I_{it} denotes internet use, B_{it} fixed broadband subscriptions, and M_{it} mobile cellular subscriptions. α_i denotes economy effects, λ_t year effects, and ε_{it} the residual. Each β coefficient describes the conditional association between one connectivity measure and the export share while retaining the other two measures. Equation 1 uses all 2,397 analytical observations across 187 economies and 15 years. The design matrix has full column rank. No additional observations were lost through lags, differencing or estimator requirements. Economy effects absorb persistent differences between economies, while year effects absorb influences shared across economies in a given year.

Uncertainty was estimated using a covariance estimator clustered by economy, with a finite sample adjustment. This permits heteroskedasticity and residual dependence within economies while assuming independence across economy clusters. Cameron and Miller, 2015, provide the basis for this inference approach. Economy clustering does not address every form of international dependence, and year effects remove only common additive annual influences. The coefficients do not identify causal effects. Connectivity and ICT exports may respond jointly to changing economic conditions, and export specialization may itself encourage communication investment. Interpretation therefore concerns conditional associations in the observed sample. Statistical precision is considered separately from substantive magnitude, with coefficients expressed in percentage points of the ICT service export share. The workbook preserves the raw panel, analytical observations, indicator identifiers, extraction routes, coverage information and source documentation. Reproduction requires the same historical extract because subsequent source revisions may alter published values. The common sample, unchanged measurement scales and explicit availability rules align the descriptive statistics with Equation 1 and make the reported sample losses traceable.

4. Methods:

4.1 Research Design and Identification Strategy:

This analysis uses an observational panel design to examine conditional associations between digital connectivity and ICT service export composition. The unit of analysis is an economy observed annually from 2010 to 2024. The estimands are the linear associations between each connectivity indicator and the ICT share of service exports, conditional on the other connectivity indicators, economy effects and year effects. The design uses changes within economies while accounting for common annual influences. Economy effects absorb persistent characteristics, including geography and enduring differences in economic structure. Year effects absorb influences shared across economies in a given year. This distinction between variation within and between observational units follows the panel interpretation discussed by Bell, Fairbrother and Jones, 2019.

The comparisons concern economies experiencing different changes in connectivity rather than treatment and control groups defined by an intervention. Consequently, the coefficients describe conditional associations. Economy and year effects do not remove changing confounders, reverse causality or measurement error. Increasing export specialization may encourage

infrastructure investment, while other economic changes may influence both connectivity and export composition. The design does not identify causal effects. The baseline specification is Equation 1, with ICT service export share as the outcome and internet use, fixed broadband subscriptions and mobile cellular subscriptions as simultaneous predictors. All variables enter contemporaneously in their published scales. Each coefficient therefore represents the association for one connectivity dimension while retaining the other two. No sampling weights are applied, so each observed economy and year combination receives equal weight.

4.2 Sample and Measurement Alignment:

Table 1 documents sample construction, while Table 3 defines the indicators and their units. The baseline estimation uses 2,397 complete observations across 187 economies. The panel is unbalanced because indicator availability varies across economies and years. All baseline coefficients use the same observations, and estimation introduces no additional losses through lags, differencing or missing controls. The outcome measures ICT service exports relative to total service exports. Its interpretation concerns export composition rather than export value. Changes can arise from movements in ICT exports, other service exports or both. Internet use measures population participation, whereas the subscription indicators measure connections per 100 people. Cellular subscription density may exceed 100 because individuals can hold multiple subscriptions. These measurement differences inform coefficient interpretation. The three connectivity indicators remain separate observed measures. They are neither combined into a composite index nor treated as interchangeable measures of a latent construct. No logarithmic transformation, normalization or standardization is applied. Coefficients for internet use represent percentage point differences in the outcome per percentage point of population use. Subscription coefficients represent percentage point differences in the outcome per additional subscription per 100 people.

Complete observation deletion determines the analytical sample. The retained observations match the complete records in the raw panel exactly. No imputation, interpolation or replacement of missing values with zero is performed. As Hughes and colleagues, 2019, explain, the implications of deletion depend on the missingness process. The resulting estimates therefore describe the observed analytical sample rather than an automatically representative population of economies. Processing preserves published numeric values. Checks examine unique economy and year identifiers, calendar coverage, completeness and admissible ranges. Extreme subscription values remain unchanged because connection density does not have a substantive upper bound of 100. No trimming or winsorization is applied.

4.3 Estimation, Statistical Inference and Diagnostics:

Ordinary least squares estimates Equation 1 using explicit economy and year indicators, with one reference category omitted from each set and an intercept retained. The design matrix contains 204 linearly independent columns. Coefficients are calculated using the least squares routine in NumPy. The implementation uses Python 3.12.14, NumPy 2.3.5, pandas 2.2.3 and SciPy 1.17.0. The calculations are deterministic and require no random seed or iterative convergence criterion. Baseline uncertainty uses a covariance estimator clustered by economy. This permits heteroskedasticity and arbitrary residual dependence within each economy while assuming independence across economy clusters. The inference approach follows Cameron and Miller, 2015. Equation 2 defines the implemented estimator.

$$\hat{V} = c\, A \left[\Sigma^{g}\, s^{g} s^{g\prime}\right] A$$

Here, $\hat{V}$ is the estimated coefficient covariance matrix . A is the inverse of X′X, where X is the full design matrix. The cluster score s^{g} equals $X^{g\prime}\hat{u}^{g}$, where X^{g} contains the design rows for economy g and $\hat{u}^{g}$ contains its fitted residuals. The summation covers all G economy clusters. The correction c equals G divided by G less one, multiplied by N less one divided by N less K. N denotes observations and K denotes estimated coefficients, including the intercept and fixed effect indicators. The baseline uses 187 clusters. Two-sided probability values and 95% confidence intervals use a student t reference distribution with 186 degrees of freedom. Statistical assessment uses a 5% significance level. Interpretation also considers coefficient magnitude and interval width rather than relying solely on threshold decisions. A clustered Wald test evaluates the joint null that the three connectivity coefficients equal zero. The quadratic Wald statistic is divided by three and assessed against an F reference distribution with three numerator degrees of freedom and 186 denominator degrees of freedom.

Collinearity assessment targets the variation relevant to Equation 1. Each predictor is first residualized against the economy and year indicators. Its residualized values are then regressed on the other two residualized predictors. The variance inflation factor is calculated as one divided by one less the resulting coefficient of determination. This procedure distinguishes overlap in the estimating variation from correlations arising from persistent differences between economies. Model fit is assessed through the reduction in residual sum of squares relative to a regression containing economy and year effects alone. This quantity measures the incremental explanatory contribution of the connectivity indicators after those effects are absorbed. It does not measure causal explanatory power or predictive performance.

4.4 Sensitivity Analysis, Interpretation and Replicability:

Three exploratory checks assess specific threats to interpretation. These checks were conducted after the baseline estimation and retain its outcome definition, predictor scales and contemporaneous timing. The first check changes inference while preserving the baseline sample and coefficients. It clusters covariance estimates by both economy and year using the additive procedure described by Cameron, Gelbach and Miller, 2011. Equation 3 specifies the combination.

$$\hat{V}^{E\gamma} = \hat{V}^{E} + \hat{V}^{\gamma} - \hat{V}^{E\cap\gamma}$$

Here, $\hat{V}^{E\gamma}$ denotes the covariance estimator allowing dependence along both dimensions . $\hat{V}^{E}$ clusters by economy , $\hat{V}^{\gamma}$ clusters by year , and $\hat{V}^{E\cap\gamma}$ clusters by their intersections. Each component applies the finite sample correction defined for Equation 2 using its respective cluster count. Because every economy and year key is unique, each intersection contains one observation. Confidence intervals and probability values use 14 reference degrees of freedom, determined by the smaller cluster dimension less one. This check addresses additional dependence but remains constrained by the availability of only 15 annual clusters. The second check restricts estimation to the 101 economies with complete observations in all 15 years, producing 1,515 observations. It assesses whether conclusions depend on intermittent indicator availability. The third restricts the observation

period to 2010 through 2019, producing 1,647 observations across 185 economies. It assesses sensitivity to including the final five years. Both restricted analyses retain economy and year effects and cluster uncertainty by economy.

Table 6 reports these comparisons. Changes under alternative clustering reflect inference alone, whereas changes under sample restrictions reflect both composition and estimating variation. Sensitivity is evaluated through direction, magnitude and uncertainty. Continued statistical significance is not treated as sufficient evidence of generalizability. The analytical sequence proceeds from the verified complete sample to descriptive statistics, pooled correlations, baseline estimation, clustered inference, collinearity assessment and exploratory sensitivity analysis. The workbook preserves the raw panel, analytical observations, source identifiers and coverage documentation. Local calculation scripts implement the design matrix, covariance estimators and restrictions described here. Reproduction requires the same historical extract because later source revisions may change observations. Together, the procedures answer the three research questions through comparable conditional associations and explicit sensitivity assessment. Their contribution rests on measurement alignment and transparent implementation of established methods rather than a new estimator or causal identification strategy.

5. Findings:

This analysis examines how internet use, fixed broadband subscriptions and mobile cellular subscriptions relate to ICT service export shares. The findings distinguish unadjusted associations from estimates accounting for economy and year effects. Sample restrictions and alternative clustering assess the sensitivity of the answers to the three research questions. The analytical sample contains 2,397 observations across 187 economies from 2010 to 2024. Complete observation requirements exclude 858 observations from the initial frame, equivalent to 26.36%. The panel is unbalanced, with 101 economies observed throughout all 15 years. All baseline estimates use the same analytical sample, ensuring that differences between predictor coefficients do not arise from different missing value rules. The distributions distinguish widespread connectivity from ICT export specialization. Internet use averages 54.89% of the population, while fixed broadband subscriptions average 14.33 per 100 people. Mobile cellular subscriptions average 110.15 per 100 people, reflecting subscription intensity rather than unique users. ICT services account for an average of 9.01% of service exports, compared with a median of 5.74%. The higher mean indicates that economies with relatively large ICT export shares influence the pooled distribution. These statistics describe export composition and do not measure the absolute value of ICT exports.

Unadjusted Pearson correlations with the export share are small: 0.0369 for internet use, 0.0521 for fixed broadband and negative 0.0156 for mobile subscriptions. By contrast, internet use and fixed broadband subscriptions correlate at 0.8014. Connectivity indicators therefore move together strongly in pooled observations without displaying comparably strong unadjusted relationships with export specialization. These pooled correlations combine differences between economies with changes within economies and cannot substitute for the adjusted estimates. Table 5 presents the baseline regression with economy and year effects. Coefficients express percentage point differences in the ICT service export share per unit of the relevant connectivity indicator. Standard errors are clustered across 187 economies, with finite sample correction. Confidence intervals and probability values use 186 degrees of freedom. This inference permits residual dependence within economies, following Cameron and Miller, 2015.

Table 5: Connectivity and ICT service export shares

Predictor	Coefficient	Clustered Standard Error	95% Confidence Interval	p Value
Internet use	−0.0201	0.0247	−0.0688 to 0.0287	0.4179
Fixed broadband subscriptions	0.2045	0.0703	0.0658 to 0.3431	0.0041
Mobile cellular subscriptions	−0.0100	0.0079	−0.0255 to 0.0056	0.2078

For RQ1, the baseline estimate does not establish a clear conditional association between internet use and ICT export specialization. A ten-percentage point increase in internet use corresponds to an estimated reduction of 0.201 percentage points in the export share, with a 95% confidence interval extending from a reduction of 0.688 to an increase of 0.287 percentage points. The interval permits associations in either direction. The estimate therefore provides insufficient evidence of a relationship at the 5% level rather than evidence that internet use has no economic relevance. This result concerns a narrower outcome than the positive internet and service trade relationship reported by Choi, 2010. Service trade can expand without ICT services gaining a larger share of the total. The present estimate consequently distinguishes participation in internet activity from specialization within service exports, without establishing whether internet use affects export values.

For RQ2, fixed broadband subscriptions display a positive conditional association with the ICT service export share. Ten additional subscriptions per 100 people correspond to an estimated increase of 2.045 percentage points, with a 95% confidence interval from 0.658 to 3.431 percentage points. The baseline probability value is 0.0041. The association is therefore statistically distinguishable from zero and has an interpretable magnitude on the outcome scale. The broadband estimate is consistent with the productive complementarity mechanism examined by Akerman, Gaarder and Mogstad, 2015. However, the present regression measures subscription density rather than worker skills, task allocation or broadband quality. Its empirical contribution is the distinction between fixed connection penetration and the other observed connectivity dimensions, rather than verification of a specific transmission mechanism.

For RQ3, the mobile subscription coefficient is negative but imprecise. Ten additional subscriptions per 100 people correspond to an estimated reduction of 0.100 percentage points in the export share. The corresponding confidence interval ranges from a reduction of 0.255 to an increase of 0.056 percentage points. The probability value of 0.2078 does not support a clear conditional association at the 5% level. This result applies to cellular subscriptions and cannot be interpreted as an estimate for mobile broadband adoption or unique mobile users. The three connectivity coefficients are jointly distinguishable from zero, with a clustered Wald F statistic of 3.446 and a probability value of 0.0178. Nevertheless, adding the connectivity indicators reduces residual variation by only 1.99% relative to a model containing economy and year effects alone. Joint statistical significance therefore coexists with limited incremental explanatory power. The estimates identify a differentiated association across connectivity dimensions rather than a comprehensive explanation of ICT export specialization.

The design matrix has full column rank. After removing economy and year effects from the predictors, variance inflation factors are 1.024 for internet use, 1.033 for fixed broadband and 1.011 for mobile subscriptions. The strong pooled correlation between internet use and broadband does not translate into substantial linear redundancy in the variation used by the regression. The uncertainty surrounding internet use and mobile subscriptions therefore cannot be attributed simply to their pooled correlation with broadband. Table 6 reports exploratory sensitivity checks conducted after the baseline estimation. Clustering by both economy and year retains the original sample and coefficients while changing uncertainty estimates. The balanced panel restriction examines sensitivity to continuous indicator availability. The restriction to 2010 through 2019 examines whether the estimates depend on the final five years of the observation period.

Table 6: Sensitivity of adjusted connectivity associations

Specification	Observations	Economies	Internet Coefficient	Internet p Value	Broadband Coefficient	Broadband p Value	Mobile Coefficient	Mobile p Value
Baseline	2,397	187	−0.0201	0.4179	0.2045	0.0041	−0.0100	0.2078
Clustering by economy and year	2,397	187	−0.0201	0.3935	0.2045	0.0080	−0.0100	0.2165
Balanced panel, 2010 to 2024	1,515	101	−0.0692	0.0061	0.1866	0.0331	−0.0050	0.4965
Restricted period, 2010 to 2019	1,647	185	−0.0068	0.8159	0.1375	0.0236	−0.0213	0.0744

The broadband association remains positive across the sensitivity checks. With clustering by both economy and year, its confidence interval is 0.0626 to 0.3463 and its probability value is 0.0080. This procedure allows dependence along both clustering dimensions, consistent with Cameron, Gelbach and Miller, 2011. The limited number of annual clusters nevertheless warrants caution in interpreting precision. In the balanced panel, the broadband coefficient is 0.1866, with a confidence interval from 0.0153 to 0.3578. During 2010 to 2019, it is 0.1375, with a confidence interval from 0.0187 to 0.2564. The positive direction persists, although the magnitude and precision vary. This pattern is compatible with the broader connection between communication infrastructure and productive international activity documented by Hjort and Poulsen, 2019, while remaining an associational result for export composition.

Internet use is more sensitive to sample coverage. Restricting the analysis to continuously observed economies produces a coefficient of negative 0.0692, with a confidence interval from negative 0.1183 to negative 0.0202. The association is statistically distinguishable from zero in that restricted sample, unlike the baseline. This change prevents a sample invariant conclusion for RQ1. It identifies sensitivity to the selected economies and their observed trajectories rather than establishing a generally negative relationship. Mobile subscriptions remain statistically indistinguishable from zero at the 5% level in every specification. The coefficient becomes more negative during 2010 to 2019, but its probability value of 0.0744 does not meet the stated criterion. Across the implemented analyses, RQ2 receives the most consistent answer: greater fixed broadband penetration accompanies a larger ICT share of service exports. RQ1 remains sensitive to sample coverage, while RQ3 provides no clear conditional association at the 5% level. These conclusions concern observed export specialization and do not establish causal effects.

6. Discussion:

Digital participation and digital export specialization are distinct economic outcomes. Table 5 shows that fixed broadband penetration has a positive conditional association with the ICT service export share, while internet use and mobile subscriptions provide less precise baseline estimates. Within Equation 1, ten additional fixed broadband subscriptions per 100 people correspond to approximately two percentage points more ICT services in total service exports. The contribution lies in distinguishing connectivity dimensions within a common international panel, rather than treating access, use and subscription intensity as interchangeable indicators. Allen, 2014, establishes that information frictions shape trade, but the present findings indicate that the observed relationship with export composition depends on how connectivity is measured. The evidence therefore refines the information cost perspective: broader communication participation does not necessarily accompany greater specialization in ICT service exports. The broadband association is consistent with reduced coordination costs, although Equation 1 identifies an aggregate relationship rather than a transmission pathway. Fixed connections can support sustained information exchange, but subscription density does not directly measure commercial use, reliability or organizational adaptation. Steinwender, 2018, demonstrates through a historical communication experiment that improved information flows can alter trade outcomes. Table 5 extends the empirical question to contemporary export composition, where the relevant outcome is the relative position of ICT services within service exports. This distinction changes the theoretical interpretation: communication improvements may facilitate international transactions without reallocating export activity toward ICT services. The present evidence supports separating the availability of communication infrastructure from the specific productive processes through which it becomes economically useful.

The clearest empirical differentiation concerns the consistency of the broadband relationship across specifications, rather than the dominance of an estimated causal channel. Table 6 preserves its positive association under alternative clustering, continuous sample coverage and the restricted observation period. Internet use, however, becomes more negative in the balanced panel, indicating that its interpretation depends on which economies remain continuously observed. Forman, Goldfarb and Greenstein, 2012, show that widespread internet diffusion can coexist with geographically concentrated economic benefits in the United States. The present results add a measurement and sample qualification to that argument: conclusions about digital participation and export specialization can change with coverage even when the regression structure remains unchanged. Thus, the comparative contribution is to identify which connectivity association persists across the implemented analytical choices without interpreting coefficient size as a share of a total effect. International comparison further clarifies why export expansion and export

specialization require separate explanations. Fernandes and colleagues, 2019, find that internet expansion supported manufacturing exports in China, whereas Malgouyres, Mayer and Mazet Sonilhac, 2021, identify increased firm imports following broadband expansion in France. These findings concern different margins of international integration. The ICT export share examined through Equation 1 can remain unchanged even when digital connectivity expands trade across several sectors. Consequently, the imprecise internet coefficient in Table 5 does not contradict evidence of trade facilitation, and the broadband coefficient does not establish a universal export response. The international contribution is an outcome specific distinction: connectivity may accompany greater participation in trade, changes in sourcing or stronger ICT specialization, and these responses cannot be inferred from one another.

The practical implication is to evaluate connectivity dimensions separately when assessing digital export strategies. Tables 5 and 6 provide a stronger empirical basis for examining fixed broadband penetration alongside ICT export composition than for using population internet use or cellular subscription totals as equivalent indicators of export readiness. They do not establish the return to infrastructure expenditure or justify a particular allocation of public investment. The limited incremental explanatory power of Equation 1 also indicates that connectivity alone provides an incomplete account of specialization. Decision makers should therefore distinguish indicators of connection availability from measures of export performance and avoid treating rising subscription totals as evidence of structural transformation. The theoretical extension is similarly bounded: digital trade frameworks gain explanatory precision when they distinguish participation, infrastructure penetration and relative sectoral outcomes.

7. Conclusion and Implications:

Digital expansion does not automatically produce internationally competitive specialization. Examined together, the three dimensions reveal an uneven relationship between connection availability, participation and export composition, with the clearest association concentrated in infrastructure penetration and other conclusions depending on sample coverage. This analysis contributes an international empirical distinction between becoming more connected and developing a stronger position in digitally delivered services. It refines information cost explanations by showing that communication indicators cannot be treated as interchangeable signals of productive specialization. The evidence supports differentiated structural associations rather than a uniform technological pathway or an identified causal mechanism. For managers, the implication is to assess communication capabilities against commercial requirements instead of interpreting rising connection totals as sufficient evidence of export readiness. For policymakers, the findings support evaluating infrastructure development alongside sectoral export composition while distinguishing connectivity objectives from export performance objectives. Operational monitoring should retain separate indicators of access, participation and commercial outcomes to prevent aggregate progress from obscuring differences in productive use. Across economies, this approach can improve the transparency of strategic assessment and reduce reliance on misleading performance signals. Its broader contribution is a framework for evaluating digital development without assuming that greater connectivity necessarily delivers equivalent economic transformation.

The observational design creates opportunities for stronger causal identification through infrastructure rollout experiments and policy discontinuities. Firm level records could connect national patterns with commercial adoption, service delivery and customer acquisition. Separating export values from export shares would clarify whether observed changes reflect ICT expansion or movements elsewhere in service trade. Measures of connection quality and business use could sharpen interpretation beyond subscription density. Further investigation of incomplete coverage could assess selection effects, while comparisons across institutional settings could establish where the observed relationships transfer. These extensions would test mechanisms and boundary conditions without presuming that aggregate associations establish causality.

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