

Digital Trade Rules and ICT Product Exports: Evidence on Clause–Product Heterogeneity

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Abstract

This study investigates why regional trade agreement (RTA) digital trade rules do not exhibit a stable average association with information and communication technology (ICT) product exports. Using a 2013–2024 panel of 72 economies, the analysis combines CEPII-BACI bilateral trade data, the UNCTAD ICT-goods classification, and TAPED digital-trade provisions. Poisson pseudo-maximum likelihood estimation retains zero trade flows and examines overall rule depth, three clause groups, clause–product interactions, Benjamini–Hochberg false-discovery-rate corrections, and stronger multidimensional fixed effects. The aggregate rule index is not robustly trade promoting, but clause–product responses differ systematically. Data-related provisions show the most consistent positive association with computers and peripherals and with consumer electronics, whereas trade-facilitation and privacy provisions are negative in selected categories. Stronger fixed effects, outcome decomposition, and an HS6 product-function test concentrate the most stable evidence in data-related provisions. The results support an offsetting-effects interpretation: heterogeneous clause–product responses can cancel one another in aggregate estimates. The analysis is interpreted as evidence of robust conditional associations rather than a quasi-experimental causal effect of individual provisions.

JEL Classification: F13; F14; F15; O33

1 Introduction

Digital trade rules have become an increasingly important component of contemporary trade governance. As digital technologies are embedded in production, distribution and after-sales services, trade agreements now address matters that were largely outside traditional border measures: cross-border data transmission, restrictions on data localisation, source-code disclosure, paperless trading, electronic authentication, personal-data protection, online consumer protection and platform responsibility. Multilateral rules have developed only gradually, so regional trade agreements (RTAs) have become a major channel through which governments experiment with and diffuse digital disciplines. This institutional shift raises a basic empirical question: do deeper digital rules systematically increase trade, or does their economic meaning depend on the type of rule and the products to which it applies?

The question is particularly relevant for ICT goods. Although they are recorded as merchandise trade, computers, communication equipment, consumer electronics, electronic components and other ICT products are increasingly bundled with digital functions. Their production and use can depend on software updates, embedded systems, remote maintenance, data interfaces, quality traceability, electronic certification and after-sales data processing. The associated trade costs therefore extend beyond tariffs, transport and conventional customs procedures. A rule that facilitates cross-border data exchange can reduce coordination costs for a product whose functionality depends on continuous software or data services. The same institutional package may nevertheless impose certification, interface-adjustment or privacy-compliance costs on other products. A uniform aggregate coefficient can consequently conceal economically meaningful heterogeneity.

Most empirical studies of digital trade governance ask whether the presence or depth of digital provisions raises trade on average. That approach is informative when the relevant institutional treatment is reasonably homogeneous, but it is less revealing when agreements bundle provisions with different functions. The starting point of this paper is precisely a missing average effect: the overall depth of RTA digital trade rules, and each of three broad clause groups when entered separately, do not display a stable positive association with ICT exports. Rather than treating this result as evidence that digital rules are ineffective, the analysis asks whether positive and negative clause–product combinations offset one another in the aggregate.

To address this issue, the paper constructs a 2013–2024 exporter–importer–ICT-category–year panel for 72 economies by combining CEPII-BACI HS2012 bilateral trade data, the UNCTAD HS2012 ICT-goods classification and the Trade Agreement Provisions on Electronic Commerce and Data (TAPED) database. The empirical design uses Poisson pseudo-maximum likelihood (PPML) estimation and retains zero trade flows. Overall digital-rule depth is decomposed into data-related provisions, trade-facilitation provisions and privacy-protection provisions. These rule groups are then interacted with five ICT product categories. The analysis further applies Wald tests, Benjamini–Hochberg false-discovery-rate (BH-FDR) correction, a stronger multidimensional fixed-effect specification, outcome decomposition and an HS6 product-function test.

The paper makes three contributions. First, it treats the absence of a stable average effect as an empirical object to be explained rather than as a null result to be discarded. Second, it proposes a clause–product matching interpretation in which the net effect of a rule depends on whether coordination and trust benefits exceed certification, system-adjustment and compliance costs for a particular product category. Third, it distinguishes levels of evidence. Conventional PPML interactions identify absolute category-specific conditional associations; the stronger fixed-effect model identifies relative category responses within the same country-pair–year; outcome decomposition and the product-function index provide complementary evidence on the economic content of the most stable pattern. This layered interpretation avoids treating every significant coefficient as an equally strong causal effect.

The principal empirical result is that data-related provisions provide the most consistent evidence of clause–product matching. In the conventional interaction model, data provisions are positively associated with computers/peripherals and consumer electronics. After multiple-testing correction and the stronger fixed-effect specification, the stable evidence continues to be concentrated in data-related provisions. By contrast, trade-facilitation and privacy provisions generate important heterogeneity in the conventional model but do not retain the same relative-category stability under the strongest fixed-effect restrictions. This pattern supports an offsetting-effects account of why overall digital-rule depth has no stable average trade-promoting coefficient.

2 Literature review and conceptual framework

2.1 Digital trade rules as heterogeneous institutional packages

Early work on digital provisions often measured whether an agreement contained an e-commerce chapter or a small set of binary clauses. Such indicators are useful for tracing the diffusion of digital governance, but they do not capture variation in policy coverage, legalisation and regulatory orientation. TAPED makes a more granular approach possible by coding preferential trade agreements across electronic-commerce, data and digital-trade topics and by distinguishing the legal strength of obligations (Burri and Polanco 2020). Related research has emphasised that digital provisions are not a single institutional technology: commitments on data openness, trade facilitation, privacy, intellectual property and platform governance can have different objectives and implementation costs (Peng et al. 2021; Hou et al. 2023).

The economic literature offers several channels through which these provisions can affect trade. Restrictions on cross-border data flows can increase the cost of digitally enabled services and of coordinating activities across borders (López González and Jouanjean 2017; López González and Ferencz 2018; Ferencz 2019; van der Marel and Ferracane 2021). Digital trade-facilitation measures can reduce documentary and processing costs, while the broader trade-facilitation literature shows that time and procedural frictions have measurable trade effects (Djankov et al. 2010; Duval et al. 2018). Privacy regulation can support trust in digital transactions, yet stricter data-processing obligations may also restrict how firms use consumer data or raise compliance expenditure (Goldfarb and Tucker 2011 2012; Goldberg et al. 2024). These mechanisms imply that institutional depth alone is unlikely to be sufficient for predicting trade effects.

Recent studies have extended the analysis from digital services to value chains, research and development flows and merchandise trade. Liu and Zhen (2022) link digital trade rules to cross-border R&D-factor flows, while Hou et al. (2023) examine the position of Chinese firms in global value chains. Ma et al. (2024) use TAPED to study trade in goods and services, and Sun et al. (2021) report effects of regional digital rules on ICT-product trade. This literature establishes that digital governance can matter beyond digitally delivered services. However, much of it still focuses on an average treatment at the level of total trade, broad sectors or an aggregate rule index. The present paper instead asks how the combination of clause function and product function can generate opposite responses inside ICT goods themselves.

2.2 ICT products, product functions and trade-cost channels

ICT goods are a useful testing ground because their physical shipment is often inseparable from digital coordination. Computers and peripherals may require operating-system and firmware updates, remote diagnostics and cloud-linked maintenance. Consumer electronics increasingly rely on data interfaces, software ecosystems and post-sale digital services. Electronic components are deeply embedded in

cross-border supply chains and may depend on data exchange for design, quality control and traceability. Communication equipment is also highly digital, but its regulatory treatment and market structure differ from the other categories. The UNCTAD HS2012 ICT-goods classification provides an ex ante, reproducible classification into five product groups rather than a grouping constructed after observing regression results.

From a structural-gravity perspective, these product functions matter because digital rules can alter category-specific bilateral trade costs. Anderson and van Wincoop (2003) and Head and Mayer (2014) show that bilateral trade reflects not only direct bilateral frictions but also multilateral resistance. The present analysis does not estimate a full general-equilibrium structural model; instead, it uses structural gravity as an organising framework for a reduced-form PPML specification. The key idea is that a clause can change the variable or fixed costs attached to a product category, and the sign of the observed trade association depends on the net balance between those effects.

Heterogeneous-firm trade theory provides an additional interpretation. Under Melitz (2003) and Chaney (2008), fixed export costs influence entry while variable trade costs affect the scale of continuing relationships. Helpman et al. (2008) similarly distinguish the extensive and intensive margins of trade. If digital provisions mainly lower the recurring costs of software updates, remote maintenance or data exchange, stronger effects should appear in the scale and continuity of existing trade. If they mainly lower fixed compliance barriers, stronger effects should appear in trade existence or new-market entry. The outcome decomposition later in the paper uses this distinction to clarify what the stable data-provision pattern represents.

2.3 Clause–product matching and hypotheses

The paper summarises the mechanism as a coordination-benefit-minus-compliance-cost framework. Data-related provisions cover cross-border data flows, restrictions on unnecessary data localisation and protection against forced disclosure of source code. These commitments can reduce the need to duplicate data infrastructure, lower the cost of cross-border software and maintenance services and limit technology-disclosure risks. Their benefits should be greatest where product functionality depends on persistent data exchange, remote updating and software integration. Accordingly, H1 predicts that data-related provisions have heterogeneous associations with ICT exports and are relatively more positive in data-coordination-intensive categories.

Trade-facilitation provisions include paperless trading, electronic authentication, electronic signatures, electronic documents and related e-commerce procedures. They can reduce documentary and transaction costs, but implementation can require certification recognition, process redesign and interface adaptation. For technologically complex products, these adjustment costs can be material in the short run. H2 therefore predicts that trade-facilitation provisions need not be positive in every category and may be negatively associated with exports where adaptation costs dominate facilitation benefits.

Privacy-protection provisions include personal-data protection, online consumer protection, rules on unsolicited commercial messages and platform-related responsibilities. Such provisions can increase institutional trust, particularly for products linked to consumer data and online services, but they can also raise compliance and data-management costs. H3 predicts a dual effect: privacy provisions may be negative in categories in which compliance pressure exceeds the trade benefit of greater institutional trust. H4 combines these arguments and predicts that clause–product combinations explain ICT trade outcomes more effectively than a single average coefficient on overall digital-rule depth.

3 Data and empirical strategy

3.1 Trade data, sample and product categories

The dependent variable is bilateral ICT-category export value. HS6 bilateral trade values are obtained from the CEPII-BACI HS2012 database and mapped to the UNCTAD HS2012 ICT-goods classification. HS6 products belonging to the same UNCTAD category are aggregated to five categories: computers and peripheral equipment (ICT01), communication equipment (ICT02), consumer electronic equipment (ICT03), electronic components (ICT04) and other ICT products (ICT05). The final panel covers 72 economies and the years 2013–2024. The sample period is chosen to maintain a consistent HS2012 product classification while capturing the period in which RTA digital provisions expanded rapidly.

The PPML sample retains zero trade flows within the defined country-pair, category and year universe. Export values are used in levels; they are not logged and no constant is added to zero observations. This is important because dropping zeros would mechanically condition the analysis on positive trade relationships and would change the estimand. PPML is well suited to non-negative trade values and to multiplicative conditional-mean models with heteroskedasticity (Santos Silva and Tenreyro 2006). Zero completion nevertheless remains a data-construction assumption: it relies on the defined sample universe being appropriate and on unreported records representing no trade rather than missing reporting. The paper therefore also reports a positive-trade robustness exercise rather than treating zero completion as untestable.

3.2 Construction of digital-rule variables

The explanatory variables are constructed from TAPED. The overall digital-rule-depth index is denoted *fta* in the source data; throughout the text it is described as overall digital-rule depth to avoid confusing the field name with a conventional free-trade-agreement dummy. The disaggregated indices are data-related provisions (*data*), trade-facilitation provisions (*prom*) and privacy-protection provisions (*priv*). The classification follows the functional logic used in the source study: data provisions cover cross-border data flows, data localisation and source-code disclosure; facilitation provisions cover World Trade Organization e-commerce disciplines, electronic-transmission treatment, domestic e-commerce frameworks, paperless trade and electronic authentication; privacy provisions cover consumer protection, personal-data protection, intermediary responsibility and unsolicited commercial communications.

TAPED distinguishes the presence and legal strength of provisions. At the provision level, absence is coded as zero, non-binding language receives a lower score, and binding or fully binding language receives higher scores. Provision scores are first aggregated within the relevant subdimensions and then to the three broad institutional modules and the overall depth measure. This hierarchical construction avoids giving a module with many individual questions disproportionate weight merely because it contains more coded items.

Agreement-level values are converted to country-pair–year variables using five rules preserved from the source design. First, country pairs without an effective RTA containing digital provisions receive zero for the digital-rule indices. Second, the agreement's depth is assigned from the year after entry into force, so the entry year itself is coded zero; this reduces the mechanical coincidence between agreement implementation and contemporaneous trade. Third, when more than one effective agreement applies to a pair in a year, the maximum applicable depth is retained to represent the highest binding rule available to that relationship. Fourth, when an agreement is upgraded or replaced, the new depth applies from the year after the upgraded arrangement enters into force. Fifth, rule values are assigned symmetrically to the two trade directions, while export values remain directional.

The baseline controls are exporter GDP, importer GDP, bilateral distance, common language, colonial ties and the bilateral gap in digital infrastructure. The three clause groups may arise from the same agreement template or the same upgrade. Their coefficients in the joint model are therefore interpreted as conditional associations within a common institutional package rather than as independent policy shocks. This is particularly important when a positive data coefficient and a negative privacy coefficient appear jointly: the estimates describe conditional components of a bundled RTA environment, not independently randomised treatments.

Table 1
Descriptive statistics and ICT-category composition

Variable / category	Mean	SD / share	Minimum	Maximum / zero share
ICT-category export value	64,124	1,100,404	0	88,643,158
Overall digital-rule depth	0.108	0.343	0	1.889
Data-related provisions	0.094	0.324	0	2.250
Trade-facilitation provisions	0.134	0.413	0	2.000
Privacy-protection provisions	0.103	0.363	0	2.250
ICT01 Computers/peripherals	77,579	24.20% of ICT exports	—	36.53% zeros
ICT02 Communication equipment	92,782	28.94%	—	39.19% zeros
ICT03 Consumer electronics	25,846	8.06%	—	39.78% zeros
ICT04 Electronic components	109,991	34.31%	—	44.92% zeros
ICT05 Other ICT products	14,421	4.50%	—	47.90% zeros
Note: The common baseline sample contains 269,490 exporter–importer–ICT-category–year observations. Source: authors’ calculations from CEPII-BACI, UNCTAD and TAPED.				

3.3 Empirical specifications and interpretation

The baseline specification is motivated by structural gravity but estimated as a reduced-form conditional-mean model. Let Export_{ijct} denote exports from economy i to j in ICT category c and year t . Rule_{ijt} is alternatively the overall rule-depth measure or one of the clause-group indices. Controls_{ijt} contains the baseline controls, and the fixed effects capture exporter, importer, year and ICT-category heterogeneity.

$$E(\text{Export}_{ijct} | X) = \exp[\alpha + \beta \text{Rule}_{ijt} + \gamma \text{Controls}_{ijt} + \lambda_i + \lambda_j + \lambda_t + \lambda_c] \quad (1)$$

The baseline standard errors are clustered by directed country pair because the dependent variable is directional. A complementary robustness check uses an undirected-pair definition because RTA provisions are normally common to both trade directions. The baseline model is not presented as a full structural-gravity estimation with exporter–product–year and importer–product–year fixed effects; rather, it is a category-level empirical model motivated by the trade-cost logic of structural gravity. The stronger model below is designed to tighten the comparison relevant to the clause–product hypothesis.

The category-interaction model multiplies each of the three clause groups by the five ICT-category indicators. This yields 15 clause–category coefficients. Wald tests first assess whether the five coefficients within each clause group are equal. Because 15 simultaneous comparisons create a

material risk of chance significance, the paper applies the Benjamini and Hochberg (1995) false-discovery-rate procedure and reports q-values. The purpose is not to make the threshold mechanically stricter than every alternative correction, but to control the expected share of false discoveries while preserving power in a setting with economically related hypotheses.

The stronger specification absorbs country-pair-year, country-pair-ICT-category and ICT-category-year fixed effects. Country-pair-year fixed effects absorb all pair-year-level rule main effects and common bilateral shocks; country-pair-category fixed effects absorb persistent comparative advantage and fixed bilateral-category trade costs; category-year fixed effects absorb global category shocks. Identification therefore comes from relative responses of categories within the same country-pair-year. Communication equipment is used as the reference category purely for normalisation. These coefficients are not substitutes for the absolute category effects from the conventional PPML model; they answer a narrower question about whether category differences remain after pair-year common factors are removed.

4 Empirical results

4.1 Average effects and the empirical puzzle

The baseline estimates establish the paper's empirical puzzle. Overall digital-rule depth is statistically insignificant when entered alone. The data, trade-facilitation and privacy indices are also insignificant when entered separately. These results do not support a simple monotonic account in which deeper digital rules uniformly increase ICT exports. When all three clause groups are entered jointly, however, the data index becomes positive and significant at the 1% level, the privacy index becomes negative and significant at the 5% level, and the trade-facilitation index remains insignificant. The joint specification therefore reveals opposing conditional associations that can disappear when aggregated into a single institutional measure.

The joint coefficients should not be interpreted as independent causal effects because the clause groups may be introduced together by the same agreement or agreement upgrade. Their value is diagnostic: they show that the null average coefficient can coexist with clause groups that point in different directions when conditioned on the rest of the institutional package. This motivates the product-category analysis rather than an attempt to select a single preferred average coefficient.

Table 2
Baseline PPML estimates

Variable	(1) Overall	(2) Data	(3) Facilitation	(4) Privacy	(5) Joint
Overall digital-rule depth	-0.0136 (0.0628)				
Data-related provisions		0.0300 (0.0591)			0.4737*** (0.1703)
Trade-facilitation provisions			-0.0144 (0.0633)		-0.1490 (0.1918)
Privacy-protection provisions				-0.0470 (0.0564)	-0.3128** (0.1523)
Observations	269,490	269,490	269,490	269,490	269,490
Clusters	4,692	4,692	4,692	4,692	4,692
Note: All models include the baseline controls and exporter, importer, year and ICT-category fixed effects. Standard errors in parentheses. ***, ** and * denote significance at 1%, 5% and 10%, respectively.					

4.2 Clause–category heterogeneity and multiple testing

The complete interaction model rejects equality across product categories for all three clause groups. For data provisions, the equality-test p-value is below 0.001; the corresponding tests for facilitation and privacy are also statistically significant. This indicates that ICT category is not merely a nuisance control but a substantive source of heterogeneity in the relationship between digital rules and trade.

Before multiple-testing correction, data provisions are positive for computers/peripherals and consumer electronics; trade-facilitation provisions are negative in the same two categories; privacy provisions are significantly negative for other ICT products. Applying BH-FDR correction to all 15 interactions leaves five core combinations. Data×ICT01 and Data×ICT03 remain positive, Facilitation×ICT01 and Facilitation×ICT03 remain negative, and Privacy×ICT05 remains negative. A 0.1-unit increase in the data index corresponds to predicted-export differences of about 10.3% for ICT01 and 14.7% for ICT03 in the conventional interaction model, while the corresponding facilitation associations are approximately – 9.5% and – 14.5%. These semi-elasticity calculations describe model-implied conditional differences rather than causal policy effects.

The pattern is economically coherent with the clause–product framework. Computers/peripherals and consumer electronics often require software updates, data interfaces and remote services, so data-opening commitments can reduce recurring coordination costs. At the same time, new electronic-authentication or procedural frameworks may require certification recognition and system adjustments

that are not costless. The privacy result for the residual ICT category is less central to the paper's mechanism and should be read more cautiously, especially because it does not retain the same relative-category strength under the stronger fixed-effect specification.

Table 3
Core clause–product combinations after BH-FDR correction

Clause–category combination	Coefficient	SE	p-value	BH-FDR q	Effect of + 0.1
Data × ICT01	0.9801	0.3864	0.011	0.042	+ 10.30%
Data × ICT03	1.3707	0.3525	< 0.001	< 0.001	+ 14.69%
Facilitation × ICT01	−0.9923	0.2708	< 0.001	0.001	−9.45%
Facilitation × ICT03	−1.5680	0.2880	< 0.001	< 0.001	−14.51%
Privacy × ICT05	−0.8211	0.3415	0.016	0.049	−7.88%
Note: Only combinations that remain significant after correction across all 15 interactions are shown. The final column reports the percentage change in predicted exports associated with a 0.1-unit increase in the relevant rule index.					

4.3 Stronger fixed effects and relative category responses

The stronger model asks whether the category pattern survives after absorbing all common country–pair–year factors and persistent pair-category heterogeneity. Because the pair-year fixed effect absorbs the rule-level main effects, the resulting coefficients are relative category effects. Using communication equipment (ICT02) as the reference category, the four relative interactions for data provisions are all positive. After BH-FDR correction, each remains significant at the 10% level and the data group is jointly significant with a Wald p-value of 0.009. The corresponding joint tests for trade facilitation and privacy are not significant.

This result creates a useful hierarchy of evidence. The conventional model indicates heterogeneity across all three clause groups, and the FDR correction shows that several individual combinations are unlikely to be chance findings. The stronger model, however, shows that only the data group retains a stable relative-category pattern after country–pair–year common shocks and long-run pair-category characteristics are absorbed. The paper therefore does not claim that facilitation and privacy are irrelevant. Rather, it treats them as important contributors to the offsetting average pattern, while locating the most robust clause–product matching evidence in data-related provisions.

Table 4
Relative category effects under stronger fixed effects

Relative interaction (base: ICT02)	Coefficient	SE	p-value	BH-FDR q
Data × ICT01	0.384*	0.174	0.027	0.084
Data × ICT03	0.359*	0.147	0.014	0.084
Data × ICT04	0.405*	0.185	0.028	0.084
Data × ICT05	0.544*	0.230	0.018	0.084
Joint Wald p-value: data	0.009			
Joint Wald p-value: facilitation	0.617			
Joint Wald p-value: privacy	0.295			
Note: Models absorb country-pair-year, country-pair-ICT-category and ICT-category-year fixed effects. * denotes $q < 0.10$ after BH-FDR correction.				

4.4 Outcome decomposition

The outcome decomposition focuses on data provisions because they provide the most stable evidence in the preceding tests. Four outcomes are considered. Trade existence indicates whether the bilateral category-year flow is positive. Positive-flow scale measures export size conditional on positive trade. ICT export share captures the category's share of bilateral ICT exports and therefore reflects composition. Continuous positive trade indicates that a positive relationship is maintained into the next period. Each exercise uses the stronger fixed-effect structure where appropriate, so the coefficients should be interpreted as relative category responses rather than as the same estimand as the baseline PPML coefficient.

The results do not point primarily to the creation of new trade relationships. Evidence for trade existence is limited: ICT01 and ICT04 reach the 10% FDR level, while the other categories do not. By contrast, positive-flow scale is strongly positive for ICT03, ICT04 and ICT05, and the export-share outcome is positive for ICT03–ICT05. Continuous positive trade is positive for all four non-reference categories and each survives BH-FDR correction at the 10% level. The stable data-provision pattern therefore appears mainly in the deepening, composition and continuity of existing trade rather than in a pure short-run entry margin.

This decomposition is consistent with the proposed coordination channel. Rules on data flows, localisation and source-code protection can reduce recurring costs associated with software maintenance, remote diagnostics and data exchange. Those cost reductions are more naturally reflected in the scale and durability of existing commercial relationships than in a discrete decision to enter a market for the first time. The decomposition is nevertheless descriptive rather than a formal mediation analysis: the observable outcomes do not directly identify firm-level mechanisms.

Table 5
Outcome decomposition for data-related provisions

Outcome	ICT01	ICT03	ICT04	ICT05
Trade existence	0.0148** [q=.042]	0.0107 [q=.120]	0.0169* [q=.075]	0.0071 [q=.258]
Positive-flow scale	0.0639 [q=.215]	0.1237** [q=.016]	0.1645*** [q=.005]	0.3120*** [q<.001]
ICT export share	0.0149 [q=.180]	0.0263*** [q=.005]	0.0334*** [q=.002]	0.0245*** [q=.005]
Continuous positive trade	0.0119* [q=.058]	0.0109* [q=.058]	0.0101* [q=.058]	0.0104* [q=.058]
Note: The models use the stronger fixed-effect structure. Brackets report BH-FDR q-values. Communication equipment is the reference category.				

5 Robustness, heterogeneity and identification limits

5.1 Alternative samples and specifications

The first robustness block re-estimates the complete 15-interaction model under four changes: excluding 2020–2021, adding a general RTA control, moving the start of the sample to 2014 and restricting the sample to positive trade flows. The five core combinations retain their baseline signs in every exercise. Most remain significant or marginally significant after BH-FDR correction, and the within-clause Wald tests continue to reject equal category coefficients in most specifications. For example, Data×ICT01 ranges from 0.904 to 1.027 in the first three alternative specifications and is 0.978 in the positive-trade sample; Data×ICT03 remains between 1.275 and 1.551. The corresponding facilitation effects remain negative and the Privacy×ICT05 coefficient remains negative.

These tests address distinct concerns. Excluding 2020–2021 reduces the possibility that pandemic-specific digitalisation or supply-chain disruption generates the pattern. Adding a general RTA control helps separate the clause interaction from a generic agreement relationship. Changing the sample start tests sensitivity to the early years of the panel. The positive-trade exercise shows that the direction of the core heterogeneity is not created solely by zero completion, although it necessarily changes the estimand by conditioning on observed trade. None of these exercises by itself provides causal identification; together they show that the basic clause–category pattern is not fragile to a single sample or modelling choice.

5.2 Product-function evidence

A further test moves from the five UNCTAD categories to HS6 product functionality. The Digital Functional Exposure Index (DFEI) averages four binary dimensions: software or firmware dependence, remote-maintenance or updating dependence, network-data interaction and user-data exposure. The index ranges from zero to one and is used only as a complementary product-function measure; it does not replace the official UNCTAD classification used in the main analysis.

At the HS6 level, the interaction between data provisions and DFEI is positive and significant (0.822, standard error 0.397). The facilitation interaction is close to zero, while Privacy×DFEI is negative and significant (− 0.913, standard error 0.454). Excluding 2020–2021 produces the same qualitative pattern: Data×DFEI is 0.800 and Privacy×DFEI is − 0.944. This evidence strengthens the interpretation that the stable data result has a product-function basis rather than being an artefact of the five-category labels. Because DFEI is a researcher-coded exposure measure, however, it remains supplementary rather than a separate identification strategy.

5.3 Import-market heterogeneity

The clause–product relationship may also depend on implementation capacity in the importing market. The sample is therefore divided into high-income and non-high-income import destinations. The signs of the five core combinations are broadly similar across groups, but FDR-adjusted significance is concentrated in high-income markets. Data×ICT03 differs significantly across the two groups at the 5% level, while Data×ICT01 differs at the 10% level. This pattern is consistent with the idea that data-rule commitments translate more effectively into trade outcomes where digital-governance capacity, regulatory implementation and compliance infrastructure are stronger.

The subgroup evidence should not be read as an exogenous treatment effect of income status. It is descriptive heterogeneity that helps delimit where the estimated clause–product match is most precisely observed. In particular, it suggests that treaty text alone does not determine economic outcomes; domestic implementation and firms' ability to use the institutional opportunities created by an agreement are also likely to matter.

5.4 Lead tests, placebo timing and identification boundary

Reverse causality and policy anticipation are important concerns because trade performance can influence the incentives to negotiate or deepen agreements. One-period lead tests therefore include the future value of each rule variable alongside the current value. The lead coefficients for overall depth, data, facilitation and privacy are all statistically insignificant in the baseline lead tests. A separate placebo exercise moves the first positive year of the data-provision index two and three years earlier and tests the relative response of the high-data-coordination categories, computers/peripherals and consumer electronics. The placebo coefficients are close to zero and insignificant in both the full and pre-treatment samples.

These diagnostics reduce concern about simple pre-trends, anticipation and mechanical reverse timing, but they do not eliminate institutional selection. Digital trade provisions evolve continuously across

agreements and do not share a common exogenous treatment date. Countries that negotiate deeper rules can differ systematically in unobserved ways from those that do not. The paper therefore maintains a deliberately bounded interpretation. Baseline interactions are conditional associations; strong-fixed-effect coefficients are relative within-pair-year category responses; DFEI and subgroup exercises are complementary mechanism and heterogeneity evidence. The results are informative about structured empirical relationships, not a quasi-natural-experiment estimate of the causal effect of signing a particular clause.

Table 6
Summary of robustness and identification diagnostics

Diagnostic	Key result	Interpretation
Exclude 2020–2021	Core signs unchanged; FDR significance largely retained	Not driven by pandemic years
Add general RTA control	Core signs unchanged	Not a mechanical general-RTA result
Positive-trade sample	Core signs unchanged	Not driven solely by zero flows
HS6 product-function test	Data×DFEI = 0.822**; Privacy×DFEI = – 0.913**	Supports a product-function basis
One-period leads	Future rule levels insignificant in baseline lead tests	Reduces simple anticipation concern
Placebo timing	–0.0085 (2-year lead); 0.0037 (3-year lead)	No pre-rule relative response
Note: The diagnostics have different estimands and should not be interpreted as independent causal identification strategies.		

5.5 Interpreting the missing average effect

Taken together, the results clarify why the average coefficient on digital-rule depth is unstable. An aggregate index combines institutional modules whose short-run trade associations need not have the same sign. It also averages across product categories with different digital functions. A positive response of data-intensive categories can therefore be offset by adaptation or compliance costs elsewhere. The absence of a significant aggregate coefficient is consequently compatible with economically meaningful structure beneath the average. This interpretation is stronger than simply selecting significant subgroup coefficients because it is supported by equality tests, correction for multiple comparisons and a stronger within-pair-year specification.

The results also show why product categories should not be treated only as fixed controls. If digital trade governance primarily changes the cost of data exchange, software support, certification and privacy compliance, then the relevant exposure varies with product functionality. The UNCTAD categories provide an ex ante classification, while the DFEI exercise supplies a finer functional check. The fact that data-related provisions remain the most stable component across these two levels of aggregation

supports the view that digital rules work through identifiable product characteristics rather than through an undifferentiated ICT-sector effect.

At the same time, the evidence cautions against interpreting the negative facilitation and privacy coefficients as proof that such rules are economically harmful. The conventional interaction model captures net conditional associations over the sample period. A negative coefficient can arise when implementation and adaptation costs are front-loaded while institutional benefits accrue more slowly, or when the clause group proxies for a broader agreement package. The stronger fixed-effect results, in which facilitation and privacy lose joint relative significance, reinforce the need for caution. The empirical contribution is therefore to document offsetting heterogeneity, not to rank the normative value of different digital-rule modules.

Finally, the distinction between absolute and relative effects matters for policy interpretation. The conventional PPML coefficients compare category-specific outcomes across country pairs and years after controlling for observed covariates and additive fixed effects. The stronger model instead asks whether, within the same country-pair-year, some ICT categories respond differently from communication equipment after absorbing persistent pair-category and common category-year shocks. Agreement between these approaches for data provisions is informative because it shows that the central pattern is visible under two different comparison sets, even though neither specification by itself removes all potential endogeneity in agreement formation.

6 Conclusion and policy implications

This paper examines why deeper RTA digital trade rules do not produce a stable average association with ICT product exports. The results support a three-step interpretation. First, overall rule depth and each clause group entered separately have no stable average trade-promoting coefficient. Second, the aggregate pattern conceals strong clause–product heterogeneity: data, trade-facilitation and privacy provisions differ in sign and magnitude across ICT categories, and five combinations survive correction for multiple testing. Third, when the comparison is tightened using country-pair–year, country-pair–category and category–year fixed effects, the most consistent evidence is concentrated in data-related provisions. Outcome decomposition and HS6 functional exposure tests point in the same direction.

The findings suggest that the economic evaluation of digital trade agreements should move beyond textual depth. A high score on the number or legalisation of provisions is not necessarily equivalent to a uniform reduction in trade costs. What matters is whether the institutional content of a clause matches the digital functions and compliance requirements of a product. For computers/peripherals and consumer electronics, commitments governing data flows, localisation and source-code protection are more closely aligned with software updates, remote maintenance, quality traceability and after-sales data processing. For facilitation and privacy rules, the estimates also reveal the possibility of short-run certification, interface and compliance costs even when the longer-run institutional objective is beneficial.

For trade policy, this implies a sequencing problem. Negotiators should not evaluate digital chapters solely by the number of obligations or by an aggregate depth index. Data-related commitments may deserve priority where export competitiveness increasingly depends on services embedded in ICT hardware. At the same time, higher-standard electronic-authentication, privacy and platform rules need complementary domestic implementation: mutual recognition, clear compliance guidance, digital-certification infrastructure and support for smaller firms that face fixed adaptation costs. Without such complementary measures, formally deeper rules may not translate into lower effective trade costs for all product groups.

The results also imply that implementation capacity in destination markets matters. The core combinations are estimated more precisely for high-income import markets, and the data–consumer-electronics difference across income groups is statistically significant. This does not justify a simple developed-versus-developing ranking, but it indicates that the same treaty language can have different commercial consequences depending on digital infrastructure, regulatory capability and firms' compliance environment. International cooperation on technical standards, authentication, data-transfer procedures and regulatory interoperability can therefore be as important as the drafting of treaty text itself.

Several limitations remain. The stable evidence concerns bundles of data-related provisions rather than the isolated causal effect of individual sub-clauses. The observable trade-existence and continuity outcomes do not substitute for firm-level entry, exit and duration data. DFEI is a rule-based product-function measure rather than a directly observed firm technology variable. Most importantly, digital provisions are institutionally selected. Lead and placebo tests do not create exogenous variation. Future research could combine firm-level trade records, product-function text data, patents or after-sales-service measures with identification strategies based on plausibly exogenous changes in international digital-rule adoption.

Declarations

Competing interests: The author declares no competing interests.

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Data availability: The study uses third-party public or licensed databases, including CEPII-BACI, UNCTAD ICT-goods classifications and TAPED. The processed analysis dataset is not publicly deposited because it integrates data from multiple source databases with their own distribution conditions. Data-construction details and replication code can be provided on reasonable request, subject to the terms of the original data providers.

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