Master's Thesis of Chaeyoung Kim

The Impact of Digitalization on Export Diversification

Analyzing Export Product and Partner Variety Extensive Margins

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Abstract

This study investigates the impact of digitalization on export diversification across two dimensions—product variety extensive margin (ProVEM) and partner variety extensive margin (ParVEM). Key digitalization variables, including internet usage and e-government, are analyzed to assess their roles in enhancing export diversification across different income levels and trade contexts.

For ProVEM, internet usage is a significant driver of export product diversification globally, with pronounced effects in high-income countries supported by advanced infrastructure and institutional capacity. E-government facilitates diversification across all product categories by reducing trade barriers and improving governance, particularly benefiting low-income countries after critical digital connectivity thresholds are surpassed.

For ParVEM, internet usage significantly contributes to export partner diversification in high-income countries, while e-government shows delayed positive effects in lagged models, highlighting the gradual impact of governance reforms. In developing countries, digitalization's impact on partner diversification remains limited until foundational digital thresholds are achieved, emphasizing the importance of infrastructure investments and complementary policies.

The findings underscore the need for tailored digitalization strategies that address the unique challenges of varying income levels and trade contexts. Investments in digital infrastructure and governance reforms are essential to fully harness the benefits of digitalization and support equitable export diversification.

Keywords: Digitalization, Export, Diversification, Extensive Margin,

Product Variety, Partner Variety

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I. Introduction

1. Research Background

The expansion of exports is a cornerstone of economic growth and a critical pathway for countries striving toward sustainable development. Export growth can be examined through two primary lenses: the intensive margin, which focuses on increasing the volume of existing exports, and the extensive margin, which emphasizes diversification. In recent years, the extensive margin—specifically export diversification, encompassing both product variety and partner variety—has drawn attention for its potential to stabilize and strengthen economic resilience. Diversifying export portfolios fosters economic growth and mitigates the risk of external shocks by reducing reliance on a limited set of markets or products. As highlighted by Amurgo-Pacheco and Pierola (2008), diversification serves as a vital mechanism for mitigating economic vulnerability, particularly for countries with limited export bases that are more exposed to global demand fluctuations and price volatility.

Export diversification has proven to be an effective strategy for economic stability, especially for countries that are heavily reliant on a few commodities. For instance, Zambia, where copper accounts for around 60% of national exports, has faced considerable economic challenges due to price volatility, supply chain disruptions, and limited market access (World Bank,

2020). In contrast, countries like Vietnam, which have shifted from an agricultural focus to a diversified export base including electronics, textiles, and footwear, have demonstrated greater economic resilience amidst global crises (IMF, 2019). Studies highlight that a diversified export portfolio not only stabilizes income flows but also contributes to structural economic transformation (Cadot et al., 2011), underscoring the necessity of export diversification for sustainable economic development.

Despite its clear advantages, achieving export diversification presents numerous challenges. Entering new markets and expanding product variety within a competitive global environment requires significant investments in innovation, infrastructure, and capacity building (OECD, 2018). Many developing nations encounter structural constraints such as high export and transportation costs, limited access to financing, inadequate infrastructure, and technological limitations (Dennis and Shepherd, 2007; UNCTAD, 2021). Institutional factors, including complex regulatory frameworks and insufficient supportive policies, further hinder diversification efforts (World Bank, 2020). These constraints illustrate the formidable barriers that countries face in pursuing diversified export portfolios.

Digitalization has emerged as a transformative solution to these challenges, offering a pathway for countries to enhance export diversification despite existing constraints. Digitalization, through improvements in ICT

infrastructure, supportive policies, and digital governance, can reduce transaction costs, expand market access, and foster innovation. Studies suggest that increased internet penetration and digital payment systems facilitate market entry by lowering information asymmetries and transaction costs (Freund and Weinhold, 2004; UNCTAD, 2019). For example, a 10% increase in internet penetration is associated with a 0.2% increase in export growth due to improved market access and reduced communication barriers (Freund and Weinhold, 2004). Moreover, digitalization enables small and medium-sized enterprises (SMEs) to overcome traditional limitations, allowing them to reach new markets and diversify product offerings with lower overhead costs.

Many developing countries have recognized the strategic value of digitalization for export diversification and are implementing initiatives aimed at building robust ICT infrastructure and adopting supportive digital policies. Rwanda's Vision 2020 plan, for instance, prioritizes ICT investments to establish the country as a regional technology hub (Rwanda Development Board, 2020). Similarly, Kenya's ICT Policy fosters an enabling environment for digital growth through regulatory reforms and incentives, aiming to support digital innovation and secure digital transactions (Kenya Ministry of ICT, 2020). Such initiatives provide a foundation for economic diversification and pave the way for advanced digital

transformations, including the digital economy, e-governance, and enhanced digital literacy.

The following chapter will outline the research purpose, delving into the specific aims and objectives of this study. By examining the relationship between digitalization and export diversification, this research aims to contribute valuable insights for policymakers and international organizations seeking to promote economic resilience through digital transformation.

2. Purpose of Research

This research investigates the role of digitalization in shaping export diversification across two distinct dimensions: Product Variety Extensive Margin (ProVEM) and Partner Variety Extensive Margin (ParVEM). Export diversification is essential for enhancing economic resilience, as it enables countries to mitigate risks, strengthen competitiveness, and stimulate economic growth by broadening their export portfolios and reaching new markets. Although digitalization has been acknowledged in the literature as a transformative force in international trade, significant gaps remain in understanding its varied impacts on different aspects of export diversification, particularly across income levels and product categories. Much of the existing research predominantly focuses on developed countries or firm-level analyses in specific regions, often overlooking the unique dynamics of digitalization in fostering export diversification within developing countries. Additionally,

prior studies frequently examine product and partner variety independently, with limited analysis of how digitalization influences both dimensions simultaneously.

This research is motivated by three primary gaps identified in the existing literature. First, while many studies consider export diversification in general terms, few distinguish between diversification in products (i.e., expanding the range of goods a country exports) and export destinations (i.e., increasing the number of markets to which products are exported). By separately analyzing product and partner variety, this research aims to provide a more granular understanding of how digitalization influences both what a country exports and where it exports. Recognizing these two distinct dimensions allows the study to capture the differentiated impacts of digitalization on export diversification, offering targeted insights that can support more precise and effective policy interventions.

Second, the effects of digitalization on export diversification are not uniform across all economic contexts. Prior research has indicated that digital tools, such as internet access, can offer benefits to lower-income countries by helping them overcome higher barriers to market entry in the global trade environment. However, digitalization's impact on product and partner diversification across different income levels remains underexplored. Similarly, there is a need for further analysis of how digitalization affects different technology levels of exported products, such as high-tech versus low-tech sectors. This study addresses these gaps by examining the impact of

digitalization on export diversification across diverse income groups and product categories, thereby providing insights for tailored digitalization strategies that cater to specific economic contexts.

Third, while digitalization has the potential to reduce informational and logistical barriers in trade, other structural factors—such as trade costs, exchange rate volatility, and market distance—may limit its effectiveness. Although existing literature emphasizes the importance of trade facilitation, few studies have examined the interaction between these barriers and digitalization's impact on export diversification. This research addresses this gap by incorporating lagged digitalization variables to capture dynamic effects and by examining how trade barriers may moderate digitalization's impact on diversification. Understanding these interactions is crucial for designing policies that maximize the benefits of digitalization in diverse trade environments.

By employing established frameworks from Hummels and Klenow (2005) and Beverelli et al. (2014), this research systematically explores digitalization's role in both product and partner diversification. It examines key digitalization indicators—such as Internet usage rates and the E-Government Index—and their differentiated effects across income levels and product categories. This study contributes to the literature by offering a deeper understanding of digitalization's influence on export diversification, informing policymakers on how to design digital and trade strategies that promote inclusive and resilient economic growth in a globalized market.

II. Literature Review

1. Export Diversification and Economic Growth

Export diversification is widely recognized as a catalyst for economic growth, as it allows countries to spread risk, enhance resilience to external shocks, and reduce dependence on a limited range of products or markets. Diversification is generally understood in two dimensions: the intensive margin and the extensive margin (Hummels and Klenow, 2005). The intensive margin refers to increasing the volume of exports for existing products in established markets, while the extensive margin involves expanding exports by introducing new products or entering new markets. Together, these dimensions provide a framework for understanding how countries expand their international trade and foster economic growth.

Hummels and Klenow (2005) introduced a framework that distinguishes between the intensive and extensive margins of trade. Their analysis shows that both dimensions are critical for achieving export growth, particularly for developing countries where diversification can reduce income volatility and stabilize the economy. Amurgo-Pacheco and Pierola (2008) further refine this framework, distinguishing between two types of extensive margins: product extensive margin (exporting new products) and geographic extensive margin (exporting existing products to new markets). Their findings highlight the importance of both types of diversification in promoting

economic growth, with a particular emphasis on the stabilizing effects of geographic diversification for developing countries.

Empirical evidence supports the positive relationship between export diversification and GDP growth. For example, Rondeau and Roudaut (2014) find that geographic diversification has a stronger impact on GDP growth than product diversification, as entering new markets allows countries to reduce dependency on single markets and better manage external risks. Their study shows that trading with developed countries can also facilitate diversification by enabling developing countries to expand their range of exported goods. Additionally, Cadot, Carrère, and Strauss-Kahn (2011) note that wealthier economies are generally better able to diversify their exports due to larger production capacities and a more extensive range of goods and services. Together, these studies underscore the importance of export diversification in fostering long-term economic growth and resilience.

2. Drivers and Barriers to Export Diversification

While export diversification can promote economic growth, it is influenced by a variety of drivers and barriers that can either facilitate or constrain a country's ability to expand its export portfolio. Key drivers of export diversification include a country's economic size, measured by GDP, which provides the resources and production capabilities necessary for diversifying exports. Larger economies often have greater capacity to expand both product

and market variety, as evidenced by the findings of Hummels and Klenow (2005) and Cadot et al. (2011), which show that countries with higher GDPs tend to achieve higher levels of diversification.

However, several barriers limit diversification efforts, particularly in developing countries. Trade costs, such as transportation expenses and compliance costs, are among the most significant obstacles to export diversification. Anderson and van Wincoop (2003) emphasize that geographical distance consistently increases trade costs, limiting a country's ability to reach diverse markets. These findings align with a study by Rondeau and Roudaut (2014), which notes that proximity to developed markets can enhance geographic diversification by reducing transportation expenses.

Exchange rate volatility is another critical barrier, as fluctuations in currency values increase the risks and costs associated with cross-border transactions. Baier and Bergstrand (2001) find that countries with high exchange rate volatility face reduced export diversification, as currency instability creates uncertainty that discourages trade. Similarly, Djankov, Freund, and Pham (2010) highlight the impact of documentation and border compliance costs on trade, demonstrating that high compliance costs inhibit market entry and reduce export diversification. Their findings indicate that addressing these structural barriers could enable countries to diversify exports more effectively, as lower trade costs and stable currency conditions create a more favorable environment for diversification.

The interaction between these drivers and barriers highlights the complex dynamics that influence export diversification. While the economic size and market proximity facilitate diversification, trade costs, and currency volatility impose constraints. This context underscores the importance of reducing structural barriers to maximize the benefits of diversification efforts, particularly in developing economies that are more vulnerable to external risks.

3. Digitalization and Export Diversification

In recent years, digitalization has emerged as a transformative factor in international trade, offering new avenues for export diversification by reducing informational, logistical, and transactional barriers. Digitalization refers to the integration of digital technology into business and government operations to improve efficiency, foster innovation, and drive economic development. Key aspects of digitalization—such as internet connectivity, ICT investment, and e-government—play an essential role in enabling countries to expand both their product and market reach, thereby promoting export diversification.

Nham et al. (2023) examine the relationship between digitalization and export diversification in 23 European countries, revealing a nonlinear, inverted U-shaped relationship between the two. Their analysis shows that the positive effects of digitalization on diversification only become

significant once a certain threshold of digital activity is reached. Key components of this threshold include digital connectivity, digital skills, internet usage, and digital public services. This finding suggests that sustained investments in digital infrastructure are necessary for countries to fully realize the diversification benefits of digital transformation.

The mechanisms through which digitalization fosters export diversification are rooted in reduced trade costs and improved logistics. Nham et al. (2023) emphasize that digitalization streamlines border compliance and documentation procedures, facilitating more efficient trade flows and enabling firms to expand both product and geographic diversification. The reduction of trade costs allows countries to access new markets and introduce new products with greater ease, enhancing their export portfolios. Qian and She (2023) further underscore the sector-specific impact of digitalization, noting that high-tech industries experience more pronounced effects from digital transformation due to their reliance on digital tools for quality improvement and market expansion.

Several studies highlight the role of digital connectivity in enabling diversification, particularly for developing countries. Gnangnon (2020) investigates the association between internet access and service export diversification, finding a positive relationship, especially in least-developed countries (LDCs). Similarly, Lapatinas (2019) finds that internet penetration is positively correlated with the sophistication and complexity of exported products, suggesting that digitalization enables countries to produce higher-

value goods and expand their product variety. These findings underscore the potential of digital infrastructure to drive product and market diversification, especially in regions where digital access is limited.

4. Research Hypotheses

The literature highlights the role of export diversification in economic growth and the complex factors that drive or constrain diversification efforts. Economic size and digitalization are key enablers of diversification, while trade costs and currency instability act as barriers, particularly in developing countries. Digitalization has the potential to mitigate these barriers, facilitating both product and geographic diversification through improved trade logistics and connectivity. To examine the relationship between digitalization and export diversification, this study will test the following hypotheses:

- **Hypothesis 1**: Digitalization positively impacts the product variety of a country's exports to its trading partners.
    - Rationale: Digitalization enables countries to diversify their export portfolios by entering new product markets. This hypothesis tests whether digital transformation initiatives help countries broaden the scope of their export offerings, allowing them to participate in a wider variety of industries and thereby increasing overall export diversification.

- **Hypothesis 2**: Digitalization positively impacts the partner variety of a country's exports of specific products across different markets.
    - Rationale: Digitalization helps a country export specific products to a greater number of destinations. With enhanced access to global markets through digital technologies, firms can reach a larger set of trading partners, potentially increasing the geographical spread of their exports. Digitalization may reduce barriers like lack of market information or inefficient logistics, thereby enabling firms to export the same product to multiple countries.

While the strength of these relationships may vary depending on specific digitalization indicators, the overall expectation is that digitalization will positively influence both product and partner diversification. This suggests that digitalization initiatives are likely to enhance export diversification, expand trading partnerships, and improve trade performance. By testing these hypotheses, this study aims to provide empirical evidence on the link between digitalization and export diversification, contributing valuable insights for policymakers and informing development strategies.

III. Empirical Strategy

1. Model Specification

This paper aims to investigate the impact of digitalization on export diversification, with a consideration of product and trading partner diversification. To achieve this, a comprehensive panel data analysis is conducted, covering 10 years from 2013 to 2022. The analysis is structured to assess both the overall global effects of digitalization on export diversification and to compare these effects by country income level. By disaggregating the analysis into income groups, the study aims to explore whether digitalization has a differential impact on export diversification depending on a country's economic status. The methodology relies on panel data econometric models to control for the country's income level and time-invariant characteristics, ensuring that the findings reflect the dynamic changes in export diversification over time due to advancements in digitalization.

To provide a holistic understanding of the effect of digitalization on export, this study applies the definitions and calculation methods for extensive margins proposed by Hummels and Klenow (2005) and Beverelli et al. (2014). Specifically, the Product Variety Extensive Margin (ProVEM) is calculated following the methodology outlined by Hummels and Klenow (2005), while the Partner Variety Extensive Margin (ParVEM) is based on the approach developed by Beverelli et al. (2014). The combination of these

methodologies can provide a comprehensive approach to capture both dimensions of the extensive margins of trade while allowing for a more specialized analysis. Hummels and Klenow (2005) provide a robust framework for measuring product variety, focusing on the contribution of new products to a country's export portfolio, which helps to isolate the impact of digitalization on product diversification. On the other hand, Beverelli et al. (2014), through their gravity model approach, offers a well-established approach for analyzing partner variety, focusing on how digitalization reduces trade costs and barriers, enabling countries to export products to a greater number of destinations. This division of methodologies allows for a deeper and more nuanced understanding of the distinct ways in which digitalization impacts both the expansion of product offerings and export markets. The specific estimation equations, which depend on the model specification, are outlined in detail in the subsequent section.

For this study, a Fixed Effects Generalized Least Squares (FE GLS) regression technique is chosen to control for time-invariant characteristics within the data. The Fixed Effect model is determined to be appropriate based on the results of the Hausman test. Additionally, to account for potential cross-sectional dependence and serial correlation within the dataset, Driscoll-Kraay standard errors are applied. This approach is effective in addressing heteroskedasticity and autocorrelation across panel units, making it particularly suitable for large panel datasets, as shown in studies that examine the economic impacts of digitalization (e.g., Gruber and Koutroumpis, 2011).

The Driscoll-Kraay standard errors provide robust standard error estimates, enhancing inference reliability when there may be interdependence across countries in a globalized setting, such as in international trade research. Combining fixed effects with Driscoll-Kraay standard errors thus offers a comprehensive framework to estimate the impact of digitalization on export diversification accurately, accounting for both within-country characteristics and cross-sectional dependencies inherent in the data. This method is increasingly used in similar studies examining digital transformation and economic outcomes, validating its relevance for analyzing export extensive margins.

a. Product Variety Extensive Margin (ProVEM)

The first part of the analysis focuses on product variety—the range of products a country exports. To quantify this, I employ the Hummels and Klenow (2005) method, which calculates the product variety index as a share of the world export basket. A panel data regression model is used to estimate the relationship between digitalization and product variety. The dependent variable is the product variety index, and the key independent variables are digitalization indicators. The model is specified as:

$$\ln(\text{ProVEM}_{it}) = \beta_1 \text{INTERNET}_{it} + \beta_2 \text{INTERNET}^2_{it} + \beta_3 \ln(\text{E-Government}_{it}) + \beta_4 \ln(\text{GDP\_REP}_{it}) + \beta_5 \ln(\text{GDP\_PART}_{jt}) + \beta_6 \ln(\text{DIST}_{ij}) + \beta_7 \ln(\text{EXCH}_{it}) + \beta_8 \ln(\text{INFL}_{it}) + \mu_i + \gamma_t + \varepsilon_{it}$$

Where:

- ln(ProVEM*it*): Log of Product Variety Extensive Margin for country *i* at time *t*, representing the range of products that a country exports as a proportion of the global export basket.
- INTERNET*it*: Internet usage rates from any location in the last three months in country *i* at time *t*.
- INTERNET^2*it*: Squared proportion of Internet usage from any location in the last three months in country *i* at time *t*.
- ln(E-Government*it*)*:* Log of E-Government Development Index in country *i* at time *t.*
- ln(GDP REP*it*): Log of GDP for the reporting country i at time *t*, indicating economic size.
- ln(GDP PART*jt*): Log of GDP for the partner country *j* at time *t*, representing the economic size of trade partners.
- ln(DIST*ij*): Log of distance between country *i* and partner country *j*.
- ln(EXCH*it*): Log of the real effective exchange rate index for country *i* at time *t*.
- ln(INFL*it*): Log of annual inflation rate in country i at time t.
- μ*i*: Country-fixed effect, controlling for unobserved, time-invariant characteristics of country *i*.
- γ*t*: Year-fixed effect, accounting for global shocks or trends over time.
- ε*it*: Error term, capturing random disturbances.

This model will test Hypothesis 1, evaluating whether higher levels of digitalization increase the variety of products a country exports.

b. Partner Variety Extensive Margin (ParVEM)

The second part of the analysis examines partner variety—the number of trading partners to which a country exports a specific product. This analysis adopts a gravity model framework, as outlined in Beverelli et al. (2014), which is well-suited to studying bilateral trade flows and partner diversification. The gravity model will be used to estimate the impact of digitalization on partner variety. The dependent variable is the log of export flows between countries and their trading partners for specific products. The model is specified as:

$$\ln(\text{ParVEM}_{ijt}) = \beta_1 \text{INTERNET}_{it} + \beta_2 \text{INTERNET}^2_{it} + \beta_3 \ln(\text{E-Government}_{it}) + \beta_4 \ln(\text{GDP\_REP}_{it}) + \beta_5 \ln(\text{DIST}_{ij}) + \beta_6 \ln(\text{EXCH}_{it}) + \beta_7 \ln(\text{INFL}_{it}) + \mu_i + \gamma_t + \varepsilon_{it}$$

Where:

- $\ln(\text{ParVEM}_{ijt})$: Log of Partner Variety Extensive Margin from country *i* to partner country *j* for specific products at time *t*, representing geographical diversification of a country's exports for a given product.
- INTERNET_{it}: Internet usage rates from any location in the last three months in country *i* at time *t*.
- INTERNET^2_{it}: Squared proportion of Internet usage from any location in the last three months in country *i* at time *t*.
- $\ln(\text{E-Government}_{it})$: Log of E-Government Development Index in country *i* at time *t*.
- $\ln(\text{GDP REP}_{it})$: Log of GDP for the reporting country *i* at time *t*, indicating economic size.
- $\ln(\text{DIST}_{ij})$: Log of distance between country *i* and partner country *j*.

- ln(EXCH$_{it}$): Log of the real effective exchange rate index for country i at time t.
- ln(INFL$_{it}$): Log of annual inflation rate in country i at time t.
- μ_i: Country-fixed effect, controlling for unobserved, time-invariant characteristics of country i.
- γ_t: Year-fixed effect, accounting for global shocks or trends over time.
- ε_{it}: Error term, capturing random disturbances.

This model will test Hypothesis 2, assessing whether digitalization facilitates the expansion of a country's export reach to a larger number of trading partners.

2. Data and Variables Description

Export Diversification Data

Export data is collected from the UN Comtrade database, providing information on the report country, partner country, export values, and product classification in a 2-digit HS code. With this data, both ProVEM and ParVEM are calculated. Products are further classified using the World Customs Organization (WCO) classification system to capture differences across product categories. The WCO classification spans categories 1 to 21. Detailed information on the WCO classifications and the corresponding HS codes can be found in the **Appendix**.

Extensive Margin Variables (ProVEM and ParVEM) Calculation

The Product Variety Extensive Margin (ProVEM) in Hummels and Klenow (2005) measures the relative importance of a country's export basket in global trade. Specifically, this method compares the set of products exported by a country to the total set of products exported globally, weighting each product by its significance in world trade. The formula for the extensive margin of product variety is:

$$\text{ProVEM}ij = \frac{\sum_{k \in K_{ij}} \text{X}_{wjk}}{\sum_{k \in K} \text{X}_{wjk}}$$

Where:

- K*ij* represents the set of products that country *i* exports to country *j*.
- X*wjk* refers to the exports of the reference country (or rest of the world, *w*) to country *j* in product *k*.
- K is the set of all products exported globally.
- $\sum_{k \in K_{ij}} \text{X}_{wjk}$ is the sum of global exports of the products that country *i* exports to country *j*.
- $\sum_{k \in K} \text{X}_{wjk}$ is the total global export value of all products to country *j*

The measure reflects how diversified a country's export portfolio is, not just by counting the number of products, but by weighting each product according to its global significance. This method captures the degree to which a country participates in the global market by exporting a variety of goods, particularly those that are more prominent in international trade.

The Partner Variety Extensive Margin (ParVEM) in Beverelli et al. (2014) focuses on the geographical diversification of exports for a given product, comparing the set of export destinations served by a country to the global distribution of that product. The formula is given by:

$$\text{ParVEM}ik = \frac{\sum_{j \in J_{ik}} \text{X}_{ijk}}{\sum_{j \in J} \text{X}_{wjk}}$$

Where:

- J*ik* represents the set of destinations to which country *i* exports product *k*.
- X*ijk* refers to the exports from country *i* to country *j* for product *k*.
- X*wjk* refers to the total global exports to country *j* for product *k*.
- J is the set of all possible destinations for product *k*.
- $\sum_{j \in J_{ik}} \text{X}_{ijk}$ is the sum of exports of product *k* from country *i* to the destination country *j*.
- $\sum_{j \in J} \text{X}_{wjk}$ is the total global export value of product *k* to all destinations.

The calculation of ParVEM captures both the presence of a country in global markets and the significance of its reach, making it a critical metric in studies of export diversification and trade policy. It is particularly relevant in the context of digital transformation, as digital tools and infrastructure can enable firms to access new markets more effectively, thereby influencing the extensive margin of export partner variety.

Digitalization Variables

Digitalization indices and initiatives are selected based on a thorough review of widely used and mentioned digital indicators from international organizations or government reports related to digital transformation. The digitalization indicators used in the analysis are internet usage (ranging from 0 to 1) and E-Government Development Index (ranging from 0 to 1). A detailed description of each variable, along with the sources of data, is provided in **Table 1**. The selection of these digitalization variables is grounded in their relevance to the mechanisms through which digitalization is expected to influence export diversification.[1] Internet usage serves as a proxy for digital connectivity and access to global markets, enabling firms to engage with international buyers and diversify their export portfolios. The E-Government Development index incorporates the access characteristics, such as the infrastructure and educational levels, to reflect how a country is using information technologies to promote access and inclusion of its people. These digital variables provide a comprehensive view of digitalization's impact on export diversification, aligning directly with the study's hypotheses on the positive effects of digitalization on product and partner variety.

1 Other digitalization-related variables were also considered, including ICT investment relative to GDP, cumulative count of enacted ICT policy, and Digital Payment Rates. However, these variables cause collinearity issues, showing similar patterns as other digital variables included in this study's model. Therefore, these variables were excluded in this analysis.

Control Variables

To account for other factors that can influence export diversification, several control variables are included in this model. GDP for both reporting countries (exporters) and partner countries (importers) are included, as larger economies tend to have more diverse export portfolios and attract more trading partners. The distance variable (DIST), representing the geographic distance between the capital cities of trading partners, is obtained from CEPII, capturing the effect of transportation costs and trade barriers associated with geographical distance.

Following Nham et al. (2023), other macroeconomic indicators are included to account for economic conditions that can impact export diversification. The exchange rate (EXCH) is included to reflect a country's trade competitiveness. Previous studies demonstrate that a stable and competitive exchange rate can enhance a country's export diversification by reducing trade uncertainties and making exports more affordable on global markets (e.g., de Piñeres and Ferrantino (1997), Latief and Lefen (2018)). Inflation (INFL) is included as a measure of macroeconomic stability; high inflation can undermine export competitiveness by raising production costs and making a country's goods less attractive to foreign markets (Bahar and Santos, 2018).

To conduct the robustness check on estimation results in the baseline model, a few other variables are added to see changes. These variables include foreign direct investment (FDI), savings (SAVE), export costs of border compliance (EC_Border) and documentary compliance (EC_Doc), the level of democratization (DEMO), and the level of corruption (CORR). Net inflow of foreign direct investment (FDI) is considered, as higher FDI inflows facilitate technological transfers and access to international markets, promoting export diversification (Agosin et al., 2012; Gnangnon, 2019). Savings (SAVE) are incorporated as they reflect domestic investment capacity, which can promote diversification (Ali, 2017). A full list of variables and their definitions and sources are described in **Table 1**.

Table 1. Description of Variables and Sources

Variables	Definition	Description	Unit	Source
ProVEM, ParVEM	Extensive Margins of Product/Partner	Extensive margin from the definition of Hummels and Klenow (2005) and Beverelli et al. (2014), derived using UN COMTRADE export data	Decimal (0 to 1)	UN COMTRADE
INTERNET	Internet usage	Proportion of individuals who used the Internet from any location in the last three months. Access can be via a fixed or mobile network	Decimal (0 to 1)	International Telecommunication Union (ITU)

E-Government	E-Government Development Index	E-Government Development index incorporates the access characteristics, such as the infrastructure and educational levels, to reflect how a country is using information technologies to promote access and inclusion of its people. The EGDI is a composite measure of three important dimensions of e-government, namely: provision of online services, telecommunication connectivity and human capacity	Decimal (0 to 1)	United Nations
GDP_REP	Reporter's GDP	Reporter (Exporter) country's GDP per capita	Current USD	World Development Indicator
GDP_PART	Partner's GDP	Partner (Importer) country's GDP per capita	Current USD	World Development Indicator
DIST	Distance	Physical distance between trading partners	Kilometers	World Bank/Geographical classification
INFL	Inflation	The annual percentage change of GDP deflator	Percent change	World Development Indicator
EXCH	Exchange rate	The real effective exchange rate index	Index (2010 = 100)	World Development Indicator

DEMO	Level of democratizatio n	The index of democratization, scaled from 0 to 10, where 10 represents a full democracy	Score index, ranging from 0 to 10	EIU Democracy Index
CORR	Corruption perception index	Perception of corruption, scaled from 1 to 100, where 0 means the highest level of perceived corruption	Score index, ranging from 1 to 100	Transparency International
EC_Doc	Export cost: documentary compliance	Cost to export, documentary compliance (USD)	USD	World Development Indicator
EC_Border	Export cost: border compliance	Cost to export, border compliance (USD)	USD	World Development Indicator
SAVE	Savings	The gross domestic saving (% of GDP)	Percent	World Development Indicator
FDI	Net inflow of foreign direct investment	The proportion of GDP	Percent	World Development Indicator

3. Descriptive Statistics

Table 2 and **Table 3** present summary statistics and correlation coefficients of variables in the model.

Table 2. Summary Statistics

Variables	**Obs**	**Mean**	**Std. dev.**	**Min**	**Max**
ln_ProVEM	2,622,224	-7.13	3.55	-29.97	0.00
ln_ParVEM	46,004	-7.39	3.36	-24.40	1.56

Internet	2,622,224	0.77	0.20	0.06	1.00
Internet_sq	2,622,224	0.63	0.25	0.00	1.00
ln_egov	2,622,224	-0.31	0.25	-1.90	-0.04
ln_gdp_part	2,622,224	9.19	1.44	5.38	11.80
ln_gdp_rep	2,622,224	9.85	1.16	5.38	11.80
ln_dist	2,622,224	8.33	0.96	4.09	9.89
ln_exch	2,087,845	4.56	0.14	3.99	5.44
ln_infl	2,608,438	2.59	0.32	-0.20	4.19
FDI	2,622,224	2.69	23.46	-440.13	234.25
SAVE	2,585,112	25.33	10.56	-23.32	64.10
ln_ec_doc	1,482,893	3.75	1.13	2.30	5.95
ln_ec_border	1,482,893	4.57	1.64	2.30	7.14
DEMO	2,622,224	7.01	1.97	1.32	9.93
CORR	2,622,224	59.20	18.31	12.00	90.00

Table 3. Correlation Matrix

A. ProVEM Correlation Coefficients

	ln_ProVEM	Internet usage	Internet_sq	ln_egov	ln_gdpreport	ln_gdppartner	ln_dist	ln_exch	ln_infl	FDI	SAVE	ln_doc	ln_bor	DEMO	CORR
ln_ProVEM	1.00														
internet	0.14	1.00													
inter_sq	0.14	0.97	1.00												
ln_egov	0.20	0.89	0.83	1.00											
ln_gdp_report	0.21	0.85	0.85	0.84	1.00										
ln_gdp_partner	-0.02	0.01	0.00	0.00	-0.01	1.00									
ln_dist	-0.22	0.02	0.03	0.06	0.06	-0.17	1.00								
ln_exch	0.05	-0.01	0.02	-0.04	0.12	0.00	-0.13	1.00							
ln_infl	-0.11	-0.38	-0.39	-0.37	-0.53	0.01	0.01	-0.14	1.00						
FDI	-0.11	0.06	0.07	0.02	0.10	0.03	-0.02	0.00	-0.04	1.00					
SAVE	0.07	0.47	0.49	0.35	0.49	-0.01	-0.01	0.17	-0.14	0.26	1.00				
ln_doc	-0.12	-0.27	-0.24	-0.29	-0.32	0.01	0.23	-0.21	0.33	0.05	-0.16	1.00			
ln_bor	-0.10	-0.23	-0.21	-0.25	-0.24	0.01	0.22	-0.26	0.27	0.07	-0.04	0.89	1.00		
DEMO	0.09	0.56	0.57	0.57	0.71	0.01	0.06	-0.18	-0.41	0.04	0.08	-0.26	-0.22	1.00	
CORR	0.15	0.73	0.79	0.68	0.88	-0.02	0.06	0.12	-0.48	0.05	0.43	-0.23	-0.19	0.77	1.00

B. ParVEM Correlation Coefficients

	ln_ParVEM	Internet usage	Internet_sq	ln_egov	ln_gdprep	ln_dist	ln_exch	ln_infl	FDI	SAVE	ln_doc	ln_bor	DEMO	CORR
ln_ParVEM	1.00													
internet	0.47	1.00												
inter_sq	0.45	0.97	1.00											
ln_egov	0.54	0.90	0.86	1.00										
ln_gdp_report	0.56	0.87	0.88	0.87	1.00									
ln_dist	0.28	-0.07	-0.07	-0.02	-0.03	1.00								
ln_exch	-0.11	-0.04	-0.03	-0.10	-0.03	-0.24	1.00							
ln_infl	-0.16	-0.33	-0.36	-0.31	-0.45	0.20	-0.09	1.00						
FDI	-0.12	0.10	0.12	0.07	0.14	-0.26	-0.03	-0.05	1.00					
SAVE	0.26	0.41	0.46	0.36	0.51	-0.05	0.03	-0.09	0.21	1.00				
ln_doc	-0.28	-0.36	-0.34	-0.38	-0.40	0.43	-0.14	0.33	-0.01	-0.13	1.00			
ln_border	-0.23	-0.27	-0.27	-0.29	-0.28	0.38	-0.21	0.27	0.02	-0.03	0.86	1.00		
DEMO	0.40	0.56	0.57	0.62	0.71	-0.08	-0.28	-0.31	0.09	0.13	-0.34	-0.26	1.00	
CORR	0.44	0.72	0.78	0.70	0.87	-0.10	-0.03	-0.43	0.10	0.43	-0.33	-0.25	0.78	1.00

The mean values of ln_ProVEM, ln_ParVEM, and digitalization variables over 10 years are presented in **Figure 1**. Panel A compares total export value with digitalization variables by year. The results show a steady increase in internet usage and e-governance over the period, particularly from 2016 onwards. While total export values exhibit fluctuations, a general upward trend aligns loosely with the digitalization variables in later years. However, the patterns of export growth and digitalization development are not perfectly synchronized, suggesting that other factors may also influence export performance.

Panel B compares the trends of ProVEM and digitalization variables such as internet usage and e-governance. The graph indicates that ProVEM exhibits fluctuations over the years, with a noticeable decline between 2019 and 2020, followed by a modest recovery in 2022. Internet usage demonstrates a steady upward trend throughout the period, suggesting increasing digital penetration globally. However, the trends of ProVEM and internet usage do not align consistently, implying that the relationship between digital connectivity and product variety may be influenced by other intervening factors. Similarly, e-governance shows a gradual upward trajectory, but its relationship with ProVEM is less clear, as ProVEM does not consistently rise alongside these improvements.

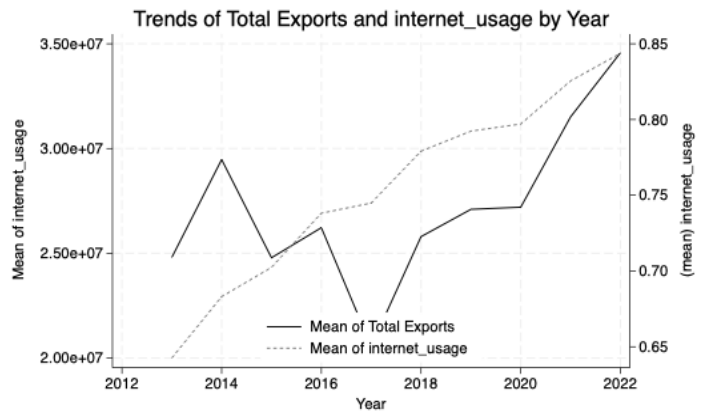
Panel C illustrates the trends in ParVEM in relation to digitalization variables. ParVEM exhibits noticeable fluctuations over the years, with a significant decline after 2018, followed by a recovery in 2022. In contrast,

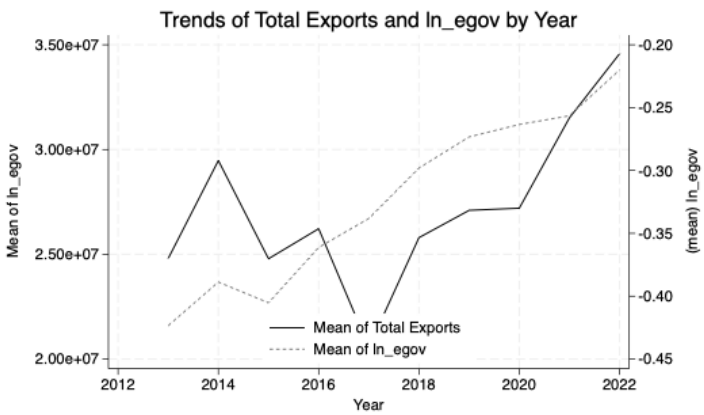
internet usage shows a consistent upward trend, suggesting that improvements in connectivity may not directly correspond to changes in partner variety. The lack of alignment between ParVEM and internet usage indicates that expanding partner variety likely requires additional factors beyond internet penetration, such as trade agreements, market access policies, and logistical enhancements. Similarly, the trends for e-governance display steady growth, but their relationship with ParVEM is not immediately apparent, as partner variety does not consistently improve alongside these advancements. These observations suggest that while digitalization may play a supporting role, partner diversification relies on a broader combination of structural, institutional, and policy-driven factors to yield meaningful impacts.

When comparing the patterns of ProVEM and ParVEM, both exhibit noticeable fluctuations over time, but their patterns differ in how they align with digitalization variables. ProVEM shows an uneven trend with periodic declines, particularly after 2018, yet it loosely aligns with the steady upward trend of internet usage, suggesting a potential, albeit delayed, influence of digitalization on product diversification. ParVEM, however, displays greater volatility, with sharper declines and a modest recovery in 2022. This indicates that expanding export partnerships is more complex and likely influenced by additional factors such as trade agreements, market conditions, and geopolitical shifts, which digitalization alone may not address.

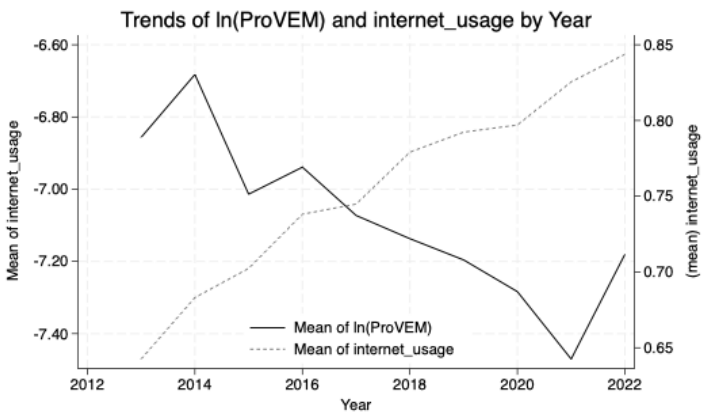
Figure 1. Trends Over Time (2013-2022)

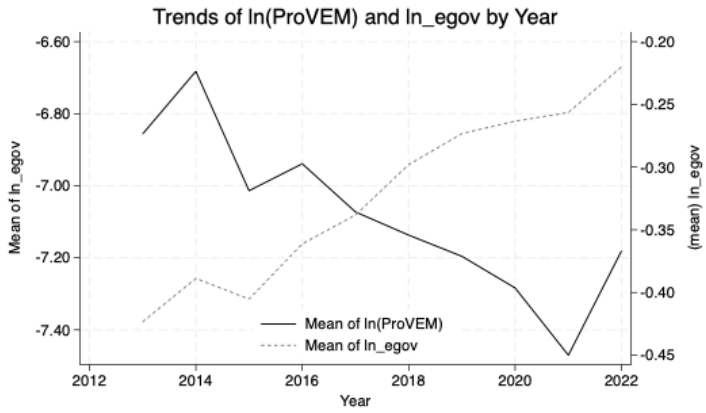
Panel A: Total Exports and Digital Variables Trend



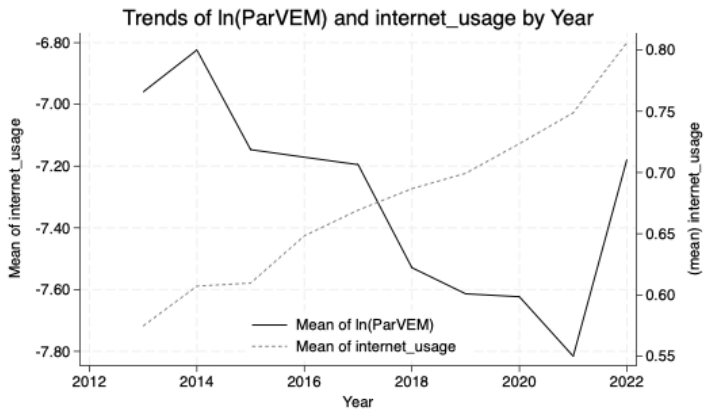


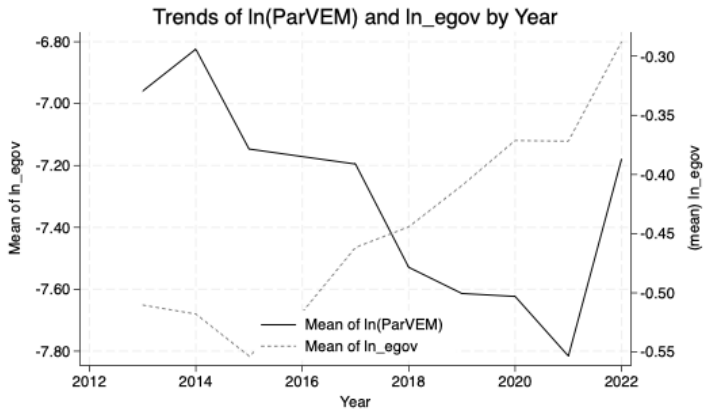
Panel B: ProVEM and Digital Variables Trend





Panel C: ParVEM and Digital Variables Trend





IV. Results and Analysis

1. Product Variety Extensive Margin Model

a. Baseline Results

The baseline regression, conducted using the Fixed Effects GLS model with Driscoll-Kraay Standard Errors, are presented in **Table 4**. The analysis is based on a dataset spanning a decade (2013–2022), comprising 2,085,168 observations from 103 countries.

ProVEM, the dependent variable, measures the export product extensive margin, which reflects the extent of a country's participation in global trade through a diverse export portfolio. Higher ProVEM values indicate a more diversified and globally integrated export portfolio.

In the regression model, including both internet usage and e-government as explanatory variables reduces the coefficients, with internet usage losing its statistical significance. This suggests that e-government might be capturing most of the explanatory power that internet usage contributes, leaving internet usage with minimal additional impact on the dependent variable. To address this issue, separate regressions were performed for each digitalization variable individually, allowing for a clearer identification of their respective impacts on ProVEM.

In the analysis of the entire global sample (Column 1), internet usage demonstrates a positive and statistically significant effect (1.018***), indicating that higher internet penetration supports export diversification.

However, internet usage squared has a significant negative coefficient (-0.531***), suggesting diminishing returns to internet connectivity as penetration increases. This highlights the critical role of internet connectivity in reducing information barriers and enabling firms to access broader markets, although its marginal benefits decline at higher levels. E-government has a positive and significant effect (0.462**), further emphasizing the importance of efficient digital governance in facilitating trade diversification.

The GDP of the reporting country shows a strongly significant positive effect (0.591***), underscoring the importance of economic size in achieving a diversified export portfolio. Similarly, the GDP of the partner country is positively associated with ProVEM (0.179***), reflecting that wealthier trading partners enhance export diversification by creating demand for a variety of products. Conversely, distance to trading partners has a negative and highly significant effect (-1.711***), indicating that geographic distance remains a major barrier to diversification due to higher trade costs. The exchange rate is also negatively significant (-0.198*), suggesting that currency depreciation may limit diversification by increasing the cost of imported inputs needed for varied production.

To assess how the impact of digitalization on ProVEM varies across different economic contexts, the data was segmented into income groups: high-income, upper-middle-income, lower-middle-income, and low-income countries. In high-income countries (Column 2), internet usage has a strong positive and significant effect (11.197***), highlighting that connectivity

remains crucial for export diversification even in advanced economies. The squared term is significantly negative (-6.790***), reinforcing the diminishing returns to internet penetration. E-government is also positively significant (1.046**), emphasizing the role of governance in supporting trade diversification. The GDP of the reporting country has a strong positive effect (0.630***), confirming that the economic scale supports export diversification. Distance remains a significant barrier (-2.260***), while exchange rate effects are insignificant.

For upper-middle-income countries (Column 3), internet usage and its squared term are both insignificant (-0.130 and -0.758, respectively), suggesting that connectivity improvements may not yet translate into diversification benefits. E-government is also insignificant (-0.304). However, the GDP of the reporting country is significantly positive (0.429**), indicating that economic size remains an important driver of export diversification. Distance to trading partners has a negative and significant effect (-1.377***), underscoring the cost of geographic separation. The exchange rate also has a negative and significant effect (-0.215**).

In lower-middle-income countries (Column 4), internet usage and its squared term are insignificant, indicating no measurable impact of connectivity on export diversification. E-government also shows no significant relationship. The GDP of the reporting country has the largest positive effect (0.990***), highlighting the critical role of economic growth in driving diversification. Distance remains a significant constraint (-

1.206***), while the exchange rate has a highly negative impact (-1.480***), showing that currency fluctuations pose significant challenges to export diversification.

In low-income countries (Column 5), internet usage has a negative and significant effect (-2.278**), suggesting that low levels of connectivity may hinder product diversification. However, the squared term is highly positive (20.964***), indicating a strong positive impact once a critical threshold of internet penetration is reached. E-government is positively significant (0.594*), emphasizing the importance of governance improvements in low-income contexts. Interestingly, the GDP of the reporting country has a large and significant negative coefficient (-8.768***), suggesting that structural challenges may prevent economic growth from translating into export diversification. The GDP of the partner country is negatively significant (-0.386), indicating limited benefits from wealthier trading partners in these contexts. The exchange rate shows a positive and significant effect (8.166***), which contrasts with other income groups and warrants further investigation.

In summary, these results reveal the distinct roles of digitalization, economic size, and trade-related factors in shaping export diversification across income groups. Internet usage supports diversification globally, with its impact strongest in high-income countries due to advanced infrastructure, while low-income countries benefit only after reaching critical adoption thresholds. In contrast, middle-income countries show no significant

relationship between internet usage and diversification, likely reflecting gaps in infrastructure or institutional readiness. E-government plays a similarly important role, positively influencing export diversification in high- and low-income countries, where governance improvements enhance trade facilitation and market access. However, its effects are minimal in middle-income countries, indicating that governance enhancements alone may not drive diversification without broader structural improvements. Economic size is a consistent positive factor, affirming the role of national GDP in facilitating export diversity. Structural constraints such as distance and exchange rate volatility remain significant barriers, especially in lower-income countries. These findings underscore the importance of tailored digital and economic policies that address the unique challenges and opportunities of each income group to foster a diverse and globally integrated export portfolio.

Table 4. Baseline Regression Results

Estimator: Fixed Effect GLS regression with Driscoll-Kraay Standard Error

Variables	ln_ProVEM				
	(1) World	(2) HIC	(3) UMIC	(4) LMI	(5) LIC
Internet_usage	1.018***	11.197***	-0.130	-0.853	-2.278*
	(0.170)	(1.109)	(0.965)	(0.540)	(0.745)
Internet_sq	-0.531***	-6.790***	-0.758	0.810	20.964***
	(0.090)	(0.610)	(0.535)	(0.480)	(1.553)

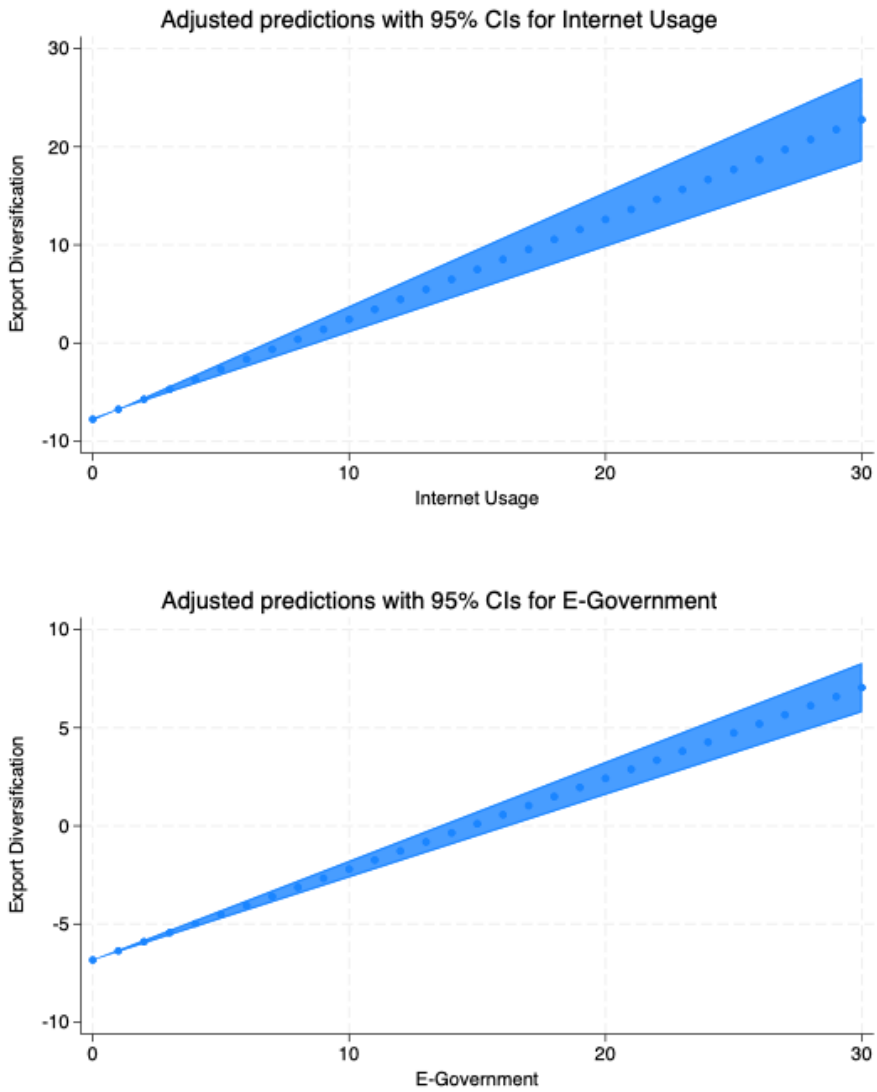
ln_egov	0.462**	1.046**	-0.304	-0.510	0.594*
	(0.123)	(0.235)	(0.183)	(0.340)	(0.178)
ln_gdp_rep	0.591***	0.630***	0.429**	0.990***	-8.768***
	(0.068)	(0.073)	(0.105)	(0.169)	(0.774)
ln_gdp_part	0.179***	0.196***	0.123***	0.024	-0.386*
	(0.008)	(0.010)	(0.015)	(0.096)	(0.132)
ln_dist	-1.711***	-2.260***	-1.377***	-1.206***	1.244*
	(0.091)	(0.110)	(0.123)	(0.265)	(0.489)
ln_exch	-0.198*	-0.190	-0.215**	-1.480***	8.166***
	(0.061)	(0.207)	(0.064)	(0.265)	(0.501)
ln_infl	0.081	0.012	0.260	-0.059	0.538***
	(0.040)	(0.018)	(0.064)	(0.063)	(0.088)
N	2085168	1558727	344963	169080	12398

Standard errors in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

Building on the baseline regression findings, the predictive margin plots in **Figure 2** provide visual confirmation and further insight into the relationship between digitalization variables and product diversification (ProVEM). The positive slope for Internet usage clearly supports the regression results, highlighting its role in enhancing export diversification. Higher internet penetration enables firms to access broader markets and leverage information networks, fostering a more diverse export portfolio. The plot for e-government similarly shows a positive upward trend, aligning with its significant positive effect in the regression results. This underscores the importance of efficient governance systems in reducing trade barriers,

improving institutional quality, and facilitating export diversification. Together, these visualizations reinforce the critical roles of digitalization components, particularly internet usage and e-government, in driving export diversification.

Figure 2. Predictive Margins of Digitalization on Export Product Diversification



b. Robustness Analysis

i. Additional Control Variables

To evaluate the consistency of key predictors' effects on product diversification, a robustness analysis is conducted by sequentially adding control variables to the baseline model. This robustness check includes political and institutional factors (DEMO and CORR), trade-related costs (ln_ec_doc and ln_ec_border), and economic indicators (SAVE and FDI). The robustness results are shown in **Table 5**, where Columns (1) and (3) represent the baseline models for internet usage and e-government, respectively, and Columns (2) and (4) incorporate corruption (CORR) and foreign direct investment (FDI) as additional controls. While most additional variables showed no statistically significant impact, corruption (CORR) and foreign direct investment (FDI) proved meaningful. CORR exhibits a small but statistically significant positive effect (0.010** in the internet usage model and 0.009** in the e-government model), suggesting that reduced corruption fosters better business environments and lowers trade barriers, enabling firms to diversify their exports. FDI also shows statistical significance (0.0001*** in both models), though its effect size is minimal. This highlights FDI’s role in providing marginal support to export diversification, likely through investments that facilitate technology transfer and infrastructure development.

In the internet usage model, the inclusion of CORR and FDI reduces the coefficient of internet usage slightly but does not alter its significance. The squared term also remains negative and significant, reaffirming diminishing returns at higher levels of internet penetration. These results confirm the robustness of internet connectivity as a driver of export diversification while highlighting the complementary effects of corruption reduction and FDI inflows.

In the e-government model, the baseline coefficient for e-government (0.462**) decreases slightly after adding CORR and FDI, but it remains statistically significant. This consistency reinforces the importance of governance improvements in enabling diversification, even when controlling for institutional quality and foreign investment.

These findings emphasize that while digitalization variables like internet usage and e-government play crucial roles in promoting export diversification, political and institutional reforms, particularly reducing corruption, and even marginal contributions from FDI enhance their effectiveness.

Table 5. Robustness Check with Additional Controls

Variables	ln_ProVEM			
	Internet Usage		E-Government	
	(1)	(2)	(3)	(4)
	Baseline	+CORR FDI	Baseline	+CORR FDI
Internet_ usage	1.018***	0.962**		

	(0.170)	(0.195)		
Internet_sq	-0.531***	-0.512**		
	(0.090)	(0.115)		
ln_egov			0.462**	0.411**
			(0.123)	(0.125)
ln_gdp_rep	0.591***	0.565***	0.557***	0.534***
	(0.068)	(0.067)	(0.055)	(0.056)
ln_gdp_part	0.179***	0.179***	0.178***	0.178***
	(0.008)	(0.008)	(0.008)	(0.008)
ln_dist	-1.711***	-1.753***	-1.593***	-1.639***
	(0.091)	(0.085)	(0.065)	(0.065)
ln_exch	-0.198*	-0.192*	-0.202**	-0.197*
	(0.061)	(0.076)	(0.052)	(0.065)
ln_infl	0.081	0.090*	0.076	0.084
	(0.040)	(0.039)	(0.038)	(0.037)
CORR		0.010**		0.009**
		(0.002)		(0.002)
FDI		0.0001***		0.0001***
		(0.000)		(0.000)
N	2085168	2085168	2085168	2085168

Standard errors in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

ii. Dynamic Specification with Lagged Variables

The next robustness check is analyzing the dynamic effects of digitalization on product diversification by introducing lagged values of key digitalization

variables. The rationale behind using lagged digitalization indicators is to mitigate potential endogeneity issues. Specifically, lagging these variables helps address reverse causality issues, as past digitalization levels are less likely to be influenced by current export diversification outcomes. This approach assumes that prior investments and policies in digital infrastructure can have a delayed effect on export diversification, making it more plausible that changes in digitalization precede and potentially drive variations in export outcomes, rather than being influenced by them.

The results of this dynamic specification are presented in **Table 6**. For internet usage, both the 1-year and 2-year lagged variables show a stronger positive effect on export diversification compared to the baseline. The 1-year lagged internet usage exhibits a significant positive coefficient, indicating that the effects of increased internet connectivity take time to materialize as firms adapt to enhanced digital infrastructure. The persistence of significant effects with a 2-year lag suggests that the benefits of internet usage are sustained over time. However, the squared term for lagged internet usage remains negative across both lag specifications, reaffirming the presence of diminishing returns as connectivity levels rise. These findings highlight that while internet usage is a critical driver of diversification, its marginal benefits decrease as digital penetration reaches higher thresholds and firms exhaust the most accessible opportunities.

For e-government, the lagged variables show stable and consistent positive effects across both the 1-year and 2-year lag models. Unlike internet

usage, the effects of e-government reforms are similar to the baseline and do not exhibit significant amplification over time. This suggests that the benefits of improved governance and institutional quality on export diversification are more immediate, likely reflecting the direct impact of reduced trade barriers and enhanced administrative efficiency on firms' export capabilities. The stability of e-government coefficients over time underscores its role as a foundational enabler of diversification, providing consistent support without requiring significant adaptation or delayed effects.

Control variables demonstrate consistent patterns across all lagged models. The GDP of the reporting country maintains a positive and significant impact on export diversification, reflecting the importance of economic size and capacity in enabling diversification. The GDP of the partner country remains positive and significant, suggesting that wealthier trading partners create demand for a broader range of products. Distance consistently exhibits a strong negative effect, highlighting persistent geographic barriers to diversification. Exchange rate volatility continues to have a negative impact, while inflation shows a weak and inconsistent positive effect.

These findings emphasize the dynamic nature of the relationship between digitalization and export diversification. The lagged effects of internet usage reveal that its benefits are not immediate but develop over time as firms adapt to new technologies and expand their market reach. In contrast, the impact of e-government is more immediate and stable, suggesting that governance improvements yield direct benefits without requiring prolonged

adjustment periods. This distinction underscores the importance of tailoring digitalization policies to align with the unique temporal dynamics of each component, ensuring sustained and complementary impacts on export diversification.

Table 6. Dynamic Effects of Digitalization on ProVEM

Variables	ln_ProVEM					
	Internet Usage			E-Government		
	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	1-Year Lag	2-Year Lag	Baseline	1-Year Lag	2-Year Lag
Internet_usage	1.018***	1.490***	1.491***			
	(0.170)	(0.092)	(0.184)			
Internet_sq	-0.531***	-0.875***	-0.937**			
	(0.090)	(0.115)	(0.194)			
ln_egov				0.462**	0.464**	0.463***
				(0.123)	(0.101)	(0.039)
ln_gdp_rep	0.591***	0.549***	0.542***	0.557***	0.513***	0.543***
	(0.068)	(0.061)	(0.066)	(0.055)	(0.044)	(0.060)
ln_gdp_part	0.179***	0.199***	0.201***	0.178***	0.197***	0.199***
	(0.008)	(0.010)	(0.011)	(0.008)	(0.010)	(0.011)
ln_dist	-1.711***	-1.656***	-1.567***	-1.593***	-1.509***	-1.467***
	(0.091)	(0.091)	(0.075)	(0.065)	(0.064)	(0.059)
ln_exch	-0.198*	-0.201**	-0.326**	-0.202**	-0.217***	-0.348**
	(0.061)	(0.046)	(0.075)	(0.052)	(0.034)	(0.082)

ln_infl	0.081	0.065	0.058	0.076	0.059	0.051
	(0.040)	(0.033)	(0.026)	(0.038)	(0.032)	(0.026)
N	2085168	1422502	1136113	2085168	1422502	1136113

Standard errors in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

iii. Heterogeneity Analysis by Product Category

The last robustness check is heterogeneity analysis by product category, meaning examining sensitivity to the category of goods in the sample. One possible assumption is that the effect of digitalization on product variety may be stronger in the high-tech product category compared to the low-tech. In categorizing products for the analysis, I used a four-tier classification approach based on technological intensity, distinguishing between traditional or non-tech, low-tech, medium-tech, and high-tech products. This classification aligns with the WCO (World Customs Organization) sections and reflects varying degrees of digitalization impact on export product variety. Certain sections—such as "Arms and Ammunition" (WCO Section 19), "Works of Art, Collectors' Pieces, and Antiques" (Section 21), "Natural or Cultured Pearls, Precious Metals, and Stones" (Section 14), and "Mineral Products" (Section 5)—are excluded in the analysis due to their limited relevance to digitalization's influence on export diversification. These product categories often respond to distinct economic factors, such as luxury market dynamics, resource availability, and security considerations, rather than digital transformation initiatives. By focusing on product categories with

more direct potential for digitalization-driven trade expansion, this approach aims to provide a clearer view of digitalization's role in promoting export diversification across technology levels.

The results, presented in **Table 7**, reveal that the effects of digitalization vary significantly across product categories. Internet usage has significant positive effects on export diversification for non-tech, low-tech, and medium-tech products. Among these, medium-tech products exhibit the largest effect, indicating that improved connectivity is especially critical for sectors reliant on moderately complex supply chains and production processes. In contrast, the effect of internet usage on high-tech products is positive but not statistically significant. This suggests that high-tech industries may depend more on specialized digital infrastructure, R&D ecosystems, and institutional supports, rather than general internet penetration. Across all categories, the squared term for internet usage is negative, confirming diminishing returns to internet usage. This effect is most pronounced for medium-tech products, where the initial benefits of connectivity are substantial but taper off as internet penetration reaches higher levels.

E-government demonstrates consistent positive and statistically significant effects for low-tech, medium-tech, and high-tech products. The effect is strongest for medium-tech products, reflecting the critical role of institutional efficiency in facilitating exports of goods with moderate technological intensity. For high-tech products, e-government also plays an

important role, highlighting the necessity of effective governance in reducing trade barriers and regulatory complexities. However, for non-tech products, the effect of e-government is positive but not statistically significant, indicating that institutional improvements are less influential in this category, which tends to rely on simpler production and trade processes.

The GDP of both reporting and partner countries shows a positive and significant relationship with export diversification across all categories, with the strongest effect observed in high-tech products. This underscores the importance of economic size and capacity in supporting advanced industries. Distance remains a significant barrier to diversification across all categories, with the largest negative impact for high-tech products. This likely reflects the logistical challenges and infrastructure requirements associated with trading in advanced goods. Exchange rate volatility negatively affects diversification, with non-tech and high-tech products being the most sensitive, reflecting their reliance on cost stability for both inputs and outputs. Inflation shows a weak and inconsistent positive effect, being statistically significant only for low-tech products, suggesting a minimal role in shaping diversification.

The heterogeneity analysis highlights that Internet usage is most impactful for medium-tech products, where it facilitates integration into global value chains. For high-tech products, the effect of internet usage is less pronounced, likely due to the greater need for specialized digital ecosystems. E-government, on the other hand, plays a significant role in low-, medium-,

and high-tech categories, underscoring the importance of governance reforms in facilitating trade for more complex products. For non-tech products, internet usage appears to be more relevant than e-government, as simpler trade processes and lower technological intensity reduce the need for advanced institutional improvements.

These findings suggest that policies aiming to enhance export diversification should be tailored to the specific needs of different product categories. Medium-tech sectors benefit most from investments in digital infrastructure, while high-tech sectors require a combination of institutional reforms and R&D support to drive diversification. Low-tech sectors can gain significantly from improved governance and trade facilitation, while non-tech sectors primarily benefit from enhanced connectivity and market access. Addressing structural trade barriers such as geographic distance and exchange rate volatility remains crucial for promoting export diversification across all categories.

Table 7. Heterogenous Effects by Product Category

Variables	ln_ProVEM			
	(1)	(2)	(3)	(4)
	Non-Tech	Low-Tech	Med-Tech	High-Tech
Internet_ usage	0.949**	0.772**	1.591***	0.836
	(0.276)	(0.190)	(0.202)	(0.391)
Internet_sq	-0.601*	-0.367**	-0.933***	-0.272

	(0.251)	(0.079)	(0.109)	(0.282)
ln_egov	0.246	0.540**	0.492***	0.505*
	(0.141)	(0.118)	(0.100)	(0.191)
ln_gdp_rep	0.523***	0.570***	0.610***	0.751***
	(0.081)	(0.083)	(0.055)	(0.074)
ln_gdp_part	0.163***	0.189***	0.181***	0.169***
	(0.032)	(0.022)	(0.022)	(0.025)
ln_dist	-1.525***	-1.739***	-1.785***	-1.811***
	(0.113)	(0.101)	(0.096)	(0.115)
ln_exch	-0.295**	-0.184*	-0.098	-0.272*
	(0.075)	(0.065)	(0.071)	(0.091)
ln_infl	0.092	0.113*	0.059	0.025
	(0.057)	(0.044)	(0.031)	(0.038)
N	480014	812496	523129	269529

Standard errors in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

2. Partner Variety Extensive Margin Model

a. Baseline Results

The baseline regression results, presented in **Table 8,** provide insights into the relationship between digitalization variables and the Partner Variety Extensive Margin (ParVEM) across different income groups. ParVEM, as defined in this analysis, measures the extent to which a country diversifies its export destinations for a given product, reflecting its geographical reach within the global market.

In the global sample (Column 1), internet usage demonstrates a positive but insignificant effect (0.472), indicating that while digital connectivity may play a role in facilitating export diversification, its effect is not universally impactful across all contexts. The squared term for internet usage remains negative (-0.122) but insignificant, suggesting no clear diminishing returns at the global level. E-government has a positive but insignificant coefficient (0.201), which may reflect the uneven implementation of governance reforms globally. Among the control variables, the GDP of the reporting country has a significant positive effect (0.468*), emphasizing the importance of economic capacity in enabling diversification. The GDP of the partner country is consistently positive (1.022***), highlighting the role of wealthier trading partners in fostering geographical diversification. Distance has a strongly significant negative effect (-1.947***), consistent with trade theory that greater geographic distance increases trade costs and limits diversification. The exchange rate also has a negative and significant effect (-0.299**), showing that currency volatility hampers diversification efforts.

In high-income countries (Column 2), internet usage continues to have a significant positive effect (4.134**), reflecting its importance even in advanced economies with established infrastructure. However, the squared term remains negative (-2.654**), reinforcing diminishing returns. E-government is positive but not significant (0.257), likely due to already efficient governance systems in these countries. The GDP of the reporting

country remains positively significant (0.193*), while the GDP of the partner country also contributes positively (0.373***). Distance has a significant negative effect (-1.944***), aligning with the traditional trade theory that geographic separation imposes higher trade costs. Exchange rate volatility is insignificant, suggesting that high-income countries are less affected by currency instability.

For upper-middle-income countries (Column 3), the effect of internet usage is positive but not significant (1.203), while the squared term remains insignificant (-0.779). This indicates that digital connectivity alone may not yet fully support export diversification in this group. E-government also has an insignificant effect (0.629), suggesting that governance reforms in these countries may not directly translate into geographical diversification benefits. The GDP of the reporting country has a significant positive effect (0.373***), indicating that economic size supports diversification. Distance remains a significant barrier (-1.628***), while exchange rate volatility negatively impacts diversification (-0.335***), highlighting the cost of currency fluctuations for this group.

In lower-middle-income countries (Column 4), internet usage has no significant effect (-0.027), while the squared term is positive but insignificant (0.341). These results suggest that connectivity improvements are insufficient to overcome other barriers, such as infrastructure deficits and trade costs. E-government has a negative and significant effect (-0.795*), indicating potential inefficiencies or misaligned governance reforms. The GDP of the

reporting country has the largest positive impact (1.058*), highlighting the critical role of economic growth. Distance remains a significant constraint (-2.591***), and exchange rate volatility has a strongly negative effect (-1.029**), showing the challenges posed by geographic and currency-related barriers.

In low-income countries (Column 5), internet usage has a large negative coefficient (-4.840), while its squared term is highly positive (39.189**), suggesting that the initial stages of digitalization may face significant inefficiencies, but the benefits become substantial after reaching a critical threshold. E-government is positive but not significant (0.610), reflecting limited institutional capacity to effectively implement reforms. Interestingly, the GDP of the reporting country shows a large negative effect (-19.03***), likely due to structural challenges that prevent economic growth from translating into diversification. The GDP of the partner country, however, has a large positive effect (8.306***), indicating reliance on wealthier trade partners for diversification. Distance has a large positive coefficient (8.306***), reflecting unique reliance on distant markets. Exchange rate volatility is positive and significant (14.84***), potentially indicating unique dynamics in low-income trade patterns.

In summary, Internet usage and e-government support diversification in high-income countries, their effects are less pronounced or inconsistent in middle- and low-income countries. Structural factors, such as economic size, geographic distance, and exchange rate volatility, consistently influence

ParVEM, underscoring the need for tailored digital and economic policies to address the unique challenges of each income group.

Table 8. Baseline Regression Results

Estimator: Fixed Effect GLS regression with Driscoll-Kraay Standard Error

Variables	ln_ParVEM				
	(1) World	(2) HIC	(3) UMIC	(4) LMI	(5) LIC
Internet_usage	0.472	4.134**	1.203	-0.027	-4.840
	(0.446)	(1.181)	(0.573)	(0.596)	(4.910)
Internet_sq	-0.122	-2.654**	-0.779	0.341	39.189**
	(2.084)	(0.666)	(0.458)	(0.607)	(8.900)
ln_egov	0.201	0.257	0.629	-0.795*	0.610
	(0.193)	(0.166)	(0.509)	(0.279)	(0.834)
ln_gdp_rep	0.468*	0.193*	0.373***	1.058*	-19.03***
	(0.161)	(0.062)	(0.057)	(0.367)	(0.865)
ln_dist	-1.947***	-1.944***	-1.628***	-2.591***	8.306***
	(0.112)	(0.072)	(0.161)	(0.446)	(0.526)
ln_exch	-0.299**	0.140	-0.335***	-1.029**	14.84***
	(0.063)	(0.106)	(0.040)	(0.281)	(1.553)
ln_infl	0.025	0.017	0.086	0.125	0.159
	(0.043)	(0.029)	(0.088)	(0.146)	(0.239)
N	32948	19650	6401	5634	1263

Standard errors in parentheses

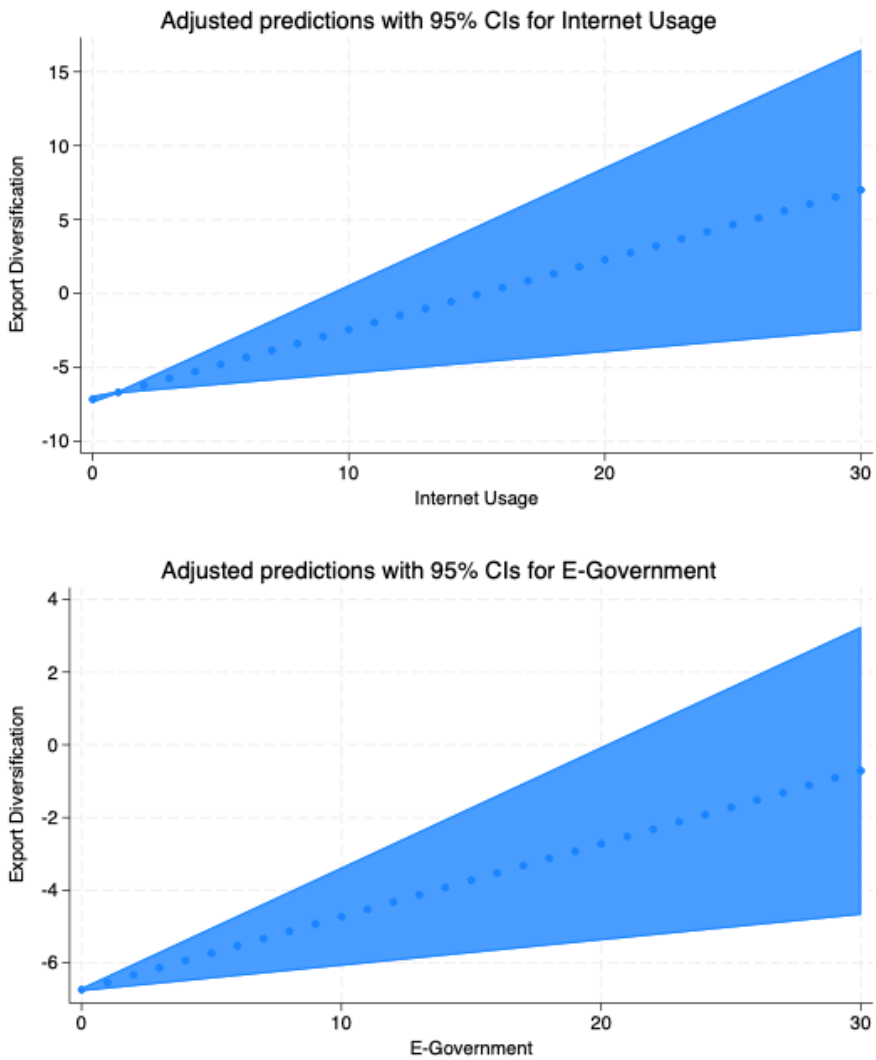
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Figure 3 illustrates the predictive margins of digitalization indicators on export partner diversification, measured by ParVEM, and explores how variations in digitalization levels impact a country's ability to diversify export destinations. The internet usage panel displays a clear positive relationship with export partner diversification. As internet usage increases, export diversification grows steadily, indicating that higher internet penetration facilitates access to a broader range of export markets. This likely reflects the role of internet connectivity in reducing informational and logistical barriers, enabling firms to reach global markets more effectively.

The e-government panel also shows a positive trend, with export partner diversification increasing alongside improvements in e-government. This result underscores the significance of governance reforms in enhancing trade facilitation and reducing bureaucratic obstacles, which are crucial for enabling firms to engage with a wider array of international markets. The confidence intervals are relatively narrower than those observed for internet usage, suggesting a more stable and consistent relationship between e-government and export diversification.

In summary, the predictive margins reveal that both internet usage and e-government are strong enablers of export partner diversification, each addressing different dimensions of the challenges associated with reaching new markets.

Figure 3. Predictive Margins of Digitalization on Export Partner Diversification



b. Robustness Analysis

i. Additional Control Variables

A robustness check of the baseline model was conducted by incrementally introducing control variables to evaluate the stability of the primary predictors in relation to export partner diversification. Similar to the robustness analysis for ProVEM, the initial model included a broader range of variables, such as

political and institutional factors (e.g., corruption and democracy), economic indicators (e.g., savings and foreign direct investment), and trade-related costs (e.g., export documentation and border compliance costs). However, the analysis revealed that only savings (SAVE) and foreign direct investment (FDI) had statistically meaningful impacts on ParVEM. Accordingly, the results for these two variables are highlighted and presented in **Table 9**.

When SAVE and FDI are included as additional controls (Columns 2 and 4), the coefficient for internet usage (Column 2) becomes positive and statistically significant (1.196**), highlighting its importance in enabling diversification when broader economic conditions are considered. The squared term for internet usage becomes significantly negative (-0.637**), indicating diminishing returns to connectivity at higher levels of penetration. In the e-government model (Column 4), the coefficient for e-government increases to 0.362 but remains statistically insignificant, suggesting that its role may be more indirect, relying on complementary factors such as trade infrastructure and policy implementation. Both SAVE and FDI emerge as significant contributors to ParVEM across models. SAVE has a consistently positive and statistically significant effect (0.007* to 0.008*), underscoring the role of domestic savings in enabling firms to invest in export-related activities and expand their geographical reach. FDI also shows a significant positive impact (0.0004**), reinforcing its critical role in supporting diversification through technology transfer, production enhancement, and integration into global trade networks.

Key control variables from the baseline model remain robust across specifications. The GDP of the reporting country retains its positive significance (0.421** to 0.445*), confirming that economic capacity consistently supports diversification by equipping firms with resources to engage with broader markets. Distance to trading partners continues to have a significant negative effect (-1.947*** to -2.028***), reflecting the enduring impact of geographical barriers on trade costs and market access. Exchange rate volatility, significant in the baseline models (-0.299**), loses its significance when SAVE and FDI are included, indicating that these macroeconomic factors mitigate some of the adverse effects of currency fluctuations. Inflation remains statistically insignificant across all specifications, suggesting that moderate inflation levels do not directly influence partner diversification outcomes.

In summary, the robustness checks with additional controls reaffirm the critical role of internet usage in promoting export partner diversification, particularly when supportive macroeconomic conditions are in place. The findings highlight the importance of FDI and domestic savings as enabling factors for diversification, suggesting that digitalization efforts must be complemented by sound financial policies to maximize their impact. E-government, while positive, does not exhibit strong direct effects, indicating that governance reforms require broader structural support to drive significant changes in ParVEM. These results emphasize the need for an integrated policy approach that combines digitalization initiatives with macroeconomic

stability and investment facilitation to foster geographical export diversification.

Table 9. Robustness Check with Additional Controls

Variables	ln_ParVEM			
	Internet Usage		E-Government	
	(1) Baseline	(2) +SAVE FDI	(3) Baseline	(4) +SAVE FDI
Internet_usage	0.472	1.196**		
	(0.446)	(0.294)		
Internet_sq	-0.122	-0.637**		
	(0.260)	(0.134)		
ln_egov			0.201	0.362
			(0.193)	(0.185)
ln_gdp_rep	0.468*	0.421**	0.445*	0.373**
	(0.161)	(0.114)	(0.153)	(0.104)
ln_dist	-1.947***	-2.028***	-1.841***	-1.802***
	(0.337)	(0.280)	(0.297)	(0.222)
ln_exch	-0.299**	-0.141	-0.299**	-0.161
	(0.063)	(0.076)	(0.066)	(0.101)
ln_infl	0.025	-0.020	0.023	-0.025
	(0.043)	(0.033)	(0.045)	(0.033)
SAVE		0.007*		0.008*
		(0.003)		(0.003)
FDI		0.0004**		0.0004*
		(0.000)		(0.000)
N	32948	32083	32948	32083

Standard errors in parentheses
* p < 0.05, ** p < 0.01, *** p < 0.001

ii. Dynamic Specification with Lagged Variables

This section explores the dynamic effects of digitalization variables on ParVEM by introducing lagged terms. Using lagged terms can be beneficial to address potential endogeneity concerns and capture delayed impacts. The results are shown in **Table 10**. In the baseline model (Columns 1 and 4), internet usage and e-government exhibit no immediate significant effects on export partner diversification, highlighting the possibility that the benefits of digitalization require time to materialize. The squared term of internet usage is also insignificant in the baseline, suggesting that diminishing returns to connectivity are not evident initially. For e-government, the baseline coefficient is positive but not statistically significant, indicating that institutional improvements alone may not instantly drive geographical diversification.

In the 1-year lagged model (Columns 2 and 5), internet usage demonstrates a highly significant and positive effect (1.661***), highlighting the delayed but substantial role of digital connectivity in expanding export destinations. This result reflects how internet penetration gradually reduces informational and logistical barriers, allowing access to a broader range of markets. However, the squared term becomes significantly negative (-0.910***), suggesting diminishing returns as connectivity increases. Similarly, e-government becomes significant with a positive coefficient (0.499*), showing that governance reforms take time to influence trade relationships effectively. These results underline the importance of

institutional improvements in fostering transparency, reducing trade costs, and facilitating broader market linkages over time.

The 2-year lagged model (Columns 3 and 6) reinforces these trends. Internet usage retains a significant positive effect (1.682**), slightly stronger than the 1-year lag, while its squared term remains significantly negative (-1.235*), confirming the non-linear relationship between connectivity and diversification. This pattern suggests that while connectivity facilitates diversification, sustaining these benefits at higher penetration levels requires complementary investments and policy measures. E-government continues to show positive and significant effects (0.487*), further emphasizing the critical role of sustained governance reforms in enabling countries to diversify their export destinations over a longer period.

Regarding the control variables, the GDP of the reporting country consistently shows positive effects across models. However, its significance diminishes in both lagged models, losing significance in the 1-year and 2-year lag models. Distance retains a negative and significant impact throughout (e.g., -1.950*** in the baseline, -2.050** in the 2-year lag), emphasizing persistent geographic barriers to diversification. Exchange rate volatility also remains negatively significant, with its effect intensifying over time (e.g., -0.299** in the baseline, -0.598** in the 2-year lag). Inflation consistently shows no significant effect, indicating it does not meaningfully influence ParVEM.

These results highlight the time-dependent nature of digitalization's impact on export partner diversification. The delayed significance of internet usage and e-government underscores the need for sustained investments in digital infrastructure and governance reforms to realize their full potential. The non-linear relationship between internet penetration and diversification suggests that policies should focus not only on expanding access but also on enhancing the quality of connectivity and addressing structural barriers such as geographic distance and exchange rate volatility. Together, these findings underscore the necessity of long-term strategies that integrate digitalization with broader trade and economic policies to foster geographically diverse export portfolios.

Table 10. Dynamic Effects of Digitalization on ParVEM

Varia-bles	ln_ParVEM					
	Internet Usage			E-Government		
	(1)	(2)	(3)	(4)	(5)	(6)
	Baseline	1-Year Lag	2-Year Lag	Baseline	1-Year Lag	2-Year Lag
Internet usage	0.472	1.661***	1.682**			
	(0.446)	(0.239)	(0.336)			
Internet_sq	-0.122	-0.91***	-1.235*			
	(0.260)	(0.122)	(0.353)			
ln_egov				0.201	0.499*	0.487*
				(0.193)	(0.156)	(0.140)

ln_gdp_rep	0.468*	0.483	0.688	0.445*	0.424	0.698*
	(0.161)	(0.210)	(0.323)	(0.153)	(0.190)	(0.287)
ln_dist	-1.95***	-1.933**	-2.05**	-1.84***	-1.639**	-1.907**
	(0.337)	(0.416)	(0.536)	(0.297)	(0.341)	(0.441)
ln_exch	-0.299**	-0.361***	-0.598**	-0.299**	-0.384***	-0.622***
	(0.063)	(0.055)	(0.121)	(0.066)	(0.056)	(0.097)
ln_infl	0.025	0.002	-0.023	0.023	-0.003	-0.025
	(0.043)	(0.031)	(0.032)	(0.045)	(0.032)	(0.023)
N	32948	24733	19767	32948	24733	19767

Standard errors in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

iii. Heterogeneity Analysis by Product Category

To further understand the relationship between digitalization and export partner diversification across different product categories, this analysis investigates the heterogeneous effects of digital infrastructure on ParVEM by product technology level: Non-Tech, Low-Tech, Medium-Tech, and High-Tech. **Table 11** presents these results.

For Non-Tech products (Column 1), internet usage shows a positive but statistically insignificant coefficient, indicating limited influence of digital connectivity on partner diversification in this category. Similarly, e-government is not significant, suggesting that governance reforms have a negligible effect on expanding export destinations for traditional products. However, the GDP of the reporting country demonstrates a significant positive effect (0.344*), highlighting the importance of economic capacity in

driving diversification even in non-technological sectors. As expected, distance has a significant negative coefficient (-1.297**), reinforcing its role as a key barrier to diversification. Exchange rate volatility is negatively significant (-0.725***), emphasizing its disruptive impact on trade in this category.

For Low-Tech products (Column 2), internet usage remains positive but statistically insignificant, while e-government shows no significant effect, suggesting that neither digital connectivity nor governance reforms are major drivers of diversification for these products. The GDP of the reporting country remains positive but insignificant, indicating a weaker influence of economic size compared to other categories. Distance continues to exert a strong negative effect (-1.932***), confirming that geographic separation hinders trade diversification. Unlike Non-Tech products, exchange rate volatility is not significant (-0.056), implying that low-tech exports may be less sensitive to currency fluctuations.

In the Medium-Tech category (Column 3), the GDP of the reporting country plays a more prominent role, with a significant positive coefficient (0.590**), underscoring its importance in enabling diversification for products requiring more advanced production and trade networks. However, internet usage (0.320) and e-government (0.006) remain statistically insignificant, indicating that digitalization does not directly influence diversification in this category. Distance retains its significant negative impact (-2.241***), highlighting the logistical costs associated with

geographic separation. Exchange rate volatility is also insignificant, suggesting limited sensitivity to currency fluctuations in this sector.

For High-Tech products (Column 4), internet usage shows a negative but insignificant coefficient, while its squared term is positive but also insignificant. This suggests that digital connectivity alone may not drive diversification in high-tech sectors, potentially due to their reliance on specialized infrastructure and targeted policies. E-government remains insignificant, indicating limited influence of governance reforms. In contrast, the GDP of the reporting country emerges as a significant positive factor (1.244**), reinforcing the role of economic capacity in supporting high-tech trade diversification. Distance has the strongest negative coefficient among all categories (-3.066**), reflecting the high logistical costs associated with high-tech exports. Exchange rate volatility (-0.524) is negative but insignificant, while inflation remains consistently irrelevant across all categories.

In summary, digitalization variables, including internet usage and e-government, have limited direct effects on export partner diversification across product categories. Economic size, as measured by the GDP of the reporting country, consistently drives diversification, with its impact being strongest in high-tech and medium-tech sectors. Distance remains a significant barrier across all categories, with the strongest negative impact observed in high-tech products. These findings underscore the need for

targeted policies addressing the unique challenges of each product category to maximize the potential of digitalization in fostering export diversification.

Table 11. Heterogenous Effects by Product Category

Variables	ln_ParVEM			
	(1)	(2)	(3)	(4)
	Non-Tech	Low-Tech	Med-Tech	High-Tech
Internet_usage	0.798	0.883	0.320	-1.567
	(0.369)	(0.423)	(0.748)	(0.883)
Internet_usage_sq	-0.254	-0.294	-0.225	1.091
	(0.226)	(0.256)	(0.440)	(0.523)
ln_egov	0.205	0.350	0.006	0.084
	(0.211)	(0.200)	(0.200)	(0.343)
ln_gdp_rep	0.344*	0.285	0.590**	1.244**
	(0.136)	(0.192)	(0.148)	(0.307)
ln_dist	-1.297**	-1.932***	-2.241***	-3.066**
	(0.305)	(0.370)	(0.305)	(0.648)
ln_exch	-0.725***	-0.056	-0.136	-0.524
	(0.103)	(0.087)	(0.065)	(0.317)
ln_infl	0.024	0.057	0.018	-0.088
	(0.048)	(0.049)	(0.025)	(0.080)
N	8870	12763	8000	3315

Standard errors in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

V. Conclusion

1. Summary of Key Findings

This paper examines how digitalization and economic factors influence the diversification of exports across product variety (ProVEM) and geographical reach (ParVEM). Through extensive empirical analysis, I explored how digitalization facilitates broader export portfolios and access to diverse export destinations across different income levels and product categories. This study offers important insights for policymakers, particularly in tailoring digitalization strategies to maximize export diversification potential in both developed and developing economies.

Product Variety Extensive Margin (ProVEM)

The analysis of product variety extensive margins (ProVEM) offers critical insights into the role of digitalization in shaping export product diversification across various contexts. At the global level, internet usage demonstrates a significant positive relationship with ProVEM, emphasizing the importance of digital connectivity in facilitating export diversification. However, diminishing returns to internet penetration are evident, indicating the necessity of surpassing a threshold to benefit from digitalization. E-government also shows a significant positive effect globally, underscoring the role of digital governance in reducing administrative barriers and enhancing export diversification opportunities. Key control variables, such as the GDP

of the reporting country and partner country, reinforce the importance of economic size in driving export diversification, while geographic distance and exchange rate volatility act as persistent barriers.

The income-group analysis reveals that the effects of digitalization vary across economic contexts. In high-income countries, internet usage has the strongest positive impact on ProVEM, supported by advanced digital infrastructure and institutional readiness. E-government also plays a significant role, reinforcing the importance of governance in facilitating trade diversification. In contrast, upper- and lower-middle-income countries show limited or insignificant effects of digitalization on ProVEM, reflecting gaps in infrastructure and institutional capacity that hinder the realization of digitalization's potential. Low-income countries present a unique pattern, where internet usage initially has a negative impact, but its squared term indicates substantial positive effects once a critical threshold of connectivity is reached. This tipping-point dynamic demonstrates the need for foundational digital infrastructure and institutional improvements in low-income countries. E-government is also significant in this group, highlighting the importance of governance reforms in overcoming structural trade barriers.

The dynamic specification with lagged digitalization variables highlights the delayed effects of digitalization on ProVEM. Internet usage exhibits stronger positive effects in the lagged models, suggesting that the benefits of connectivity materialize over time as firms adapt to new technologies and market opportunities. However, the diminishing returns

remain evident, as the squared term becomes increasingly negative in the lagged models. E-government also shows delayed positive effects, reflecting the time required for governance reforms to translate into tangible trade benefits. These findings emphasize the importance of considering the temporal dimension of digitalization when designing policies to promote export diversification.

Finally, the heterogeneity analysis by product category reveals varying impacts of digitalization based on the technological intensity of products. Internet usage is significant for non-tech, low-tech, and medium-tech products, with its strongest effects observed in the medium-tech category. This suggests that digital infrastructure plays a pivotal role in enabling diversification within moderately complex sectors. E-government consistently demonstrates positive effects across low-tech, medium-tech, and high-tech categories, highlighting its role in streamlining trade processes and reducing barriers. However, digitalization appears less impactful for high-tech products, likely due to the need for more specialized infrastructure and targeted policies to support diversification in this category.

In summary, the findings underscore the multifaceted role of digitalization in enhancing ProVEM, with its effects varying across income groups, time horizons, and product categories. Internet usage is a key driver of diversification globally, particularly in high-income countriess and medium-tech industries, while low-income countries benefit from digitalization after overcoming initial structural challenges. E-government

complements these effects by facilitating trade across diverse contexts, particularly in low- and high-tech sectors. Tailored strategies that address the unique challenges faced by different income groups and product categories are essential to ensure the equitable distribution of digitalization's benefits and to maximize its potential for driving export diversification.

Partner Variety Extensive Margin (ParVEM)

The analysis of partner variety extensive margins (ParVEM) highlights the role of digitalization in shaping export partner diversification across countries and product categories. At the global level, internet usage demonstrates a positive but initially insignificant relationship with ParVEM in the baseline model, while its impact becomes statistically significant with the inclusion of additional controls, such as savings and foreign direct investment (FDI). Diminishing returns to internet usage suggest that the benefits of connectivity plateau after reaching higher penetration levels. E-government shows a positive but insignificant effect in the baseline model, though it gains statistical significance when controls are added, underscoring its role in reducing administrative trade barriers and facilitating export partner diversification.

The income-group analysis reveals distinct patterns in how digitalization affects ParVEM across different economic contexts. In high-income countries (HICs), internet usage significantly supports export partner diversification, though diminishing returns are observed due to infrastructure

saturation. E-government has no significant effect, likely reflecting already efficient governance systems. In upper-middle-income countries (UMICs), neither internet usage nor e-government significantly impacts ParVEM, suggesting limitations in infrastructure and governance that impede digitalization's potential. For lower-middle-income countries (LMICs), internet usage shows no significant effect, while e-government exhibits a negative relationship, possibly reflecting misaligned or inefficient governance reforms. In low-income countries (LICs), internet usage initially has a negative impact, likely due to structural challenges like inadequate infrastructure and high connectivity costs. However, a positive squared term indicates that substantial diversification gains are achievable once foundational digital thresholds are met. E-government remains insignificant in LICs, suggesting governance reforms alone are insufficient without concurrent investments in infrastructure and supportive policies.

The dynamic analysis of lagged digitalization variables further illustrates the delayed effects of digitalization on ParVEM. Internet usage demonstrates stronger positive effects in the 1-year and 2-year lagged models, highlighting that the benefits of connectivity materialize over time as firms adapt to new market opportunities and logistical systems. The negative squared term for internet usage persists, reinforcing the concept of diminishing returns. Similarly, e-government exhibits delayed positive effects in lagged models, reflecting the time required for governance reforms to effectively reduce barriers and facilitate trade. These findings emphasize

the importance of considering the temporal dimension of digitalization's impact when formulating trade policies.

Finally, the heterogeneity analysis by product category reveals no statistically significant effects of digitalization variables—either internet usage or e-government—on ParVEM for any product category. This suggests that digitalization's impact on export partner diversification may not directly vary by the technological intensity of products, as other structural factors, such as supply chain integration, trade policy frameworks, and sector-specific dynamics, might play a larger role in shaping diversification patterns.

In conclusion, internet usage emerges as a significant driver of partner diversification in HICs, though its benefits taper off at higher levels of penetration. LICs exhibit a unique tipping-point effect, where substantial diversification gains are observed after surpassing foundational connectivity thresholds. E-government complements these effects by facilitating trade in contexts with effective governance, though its impact is limited without supportive infrastructure.

2. Policy Implications

The findings presented in the analyses of ProVEM and ParVEM highlight several critical policy insights for governments, trade practitioners, and development organizations seeking to enhance export diversification through digitalization. These insights emphasize the need for targeted interventions

that address the specific challenges and opportunities faced by countries across varying income levels and technological contexts.

For developing economies, expanding foundational digital infrastructure should be a top priority. Investments in internet connectivity and governance systems are critical for achieving meaningful export diversification, as demonstrated by the tipping-point dynamics observed in low-income countries. These dynamics highlight that substantial gains in export partner and product variety become achievable once foundational connectivity thresholds are surpassed. Complementary policies, such as reducing regulatory burdens, streamlining customs procedures, and fostering trade facilitation measures, are equally essential to maximize the potential benefits of digitalization. This aligns with UNCTAD (2019), which emphasizes the role of digital connectivity in lowering trade barriers and enabling diversification.

For advanced economies, where digital infrastructure is already mature, digital policies should focus on optimizing existing systems and fostering innovation. The observed positive impact of internet usage on high-tech exports in ProVEM indicates opportunities for these countries to leverage digitalization to strengthen competitiveness in technologically advanced sectors. Policymakers in high-income countries should prioritize initiatives that support cutting-edge technological infrastructure and innovation ecosystems to maintain their competitive edge in global markets.

Addressing structural barriers is crucial for all income groups to

amplify the benefits of digitalization. Geographic distance and exchange rate volatility persist as significant constraints on export diversification across ProVEM and ParVEM analyses. Policymakers must prioritize investments in transport and logistics infrastructure to lower trade costs and improve market access. Concurrently, macroeconomic stability measures, such as managing exchange rate fluctuations, are necessary to create a conducive environment for trade expansion. These strategies are particularly important for emerging economies, where logistical and financial barriers to trade remain more pronounced.

Sector-specific approaches should also be considered, given the varied impacts of digitalization across product categories. For ProVEM, digital connectivity significantly supports diversification in non-tech, low-tech, and medium-tech sectors, with particularly strong effects observed in medium-tech industries. This underscores the importance of aligning digital infrastructure policies with the needs of moderately complex sectors, which can benefit substantially from improved connectivity and governance. However, the lack of significant effects of digitalization on ParVEM across product categories suggests that broader structural factors, such as supply chain integration, trade agreements, and sectoral dynamics, play a larger role in shaping export partner diversification. Policymakers should therefore complement digitalization initiatives with comprehensive trade and industrial policies tailored to the unique characteristics of specific sectors.

In conclusion, the findings underscore the multifaceted role of digitalization in promoting export diversification and offer actionable guidance for policymakers. For developing countries, investments in foundational infrastructure and governance reforms are essential to unlock digitalization's transformative potential. Advanced economies should focus on maintaining competitiveness in high-tech sectors through innovation-driven policies. Across all contexts, addressing structural and logistical barriers is critical to amplifying the positive effects of digitalization. A holistic, tailored approach is necessary to ensure that digital tools and governance reforms effectively foster export diversification in a rapidly evolving global trade landscape.

3. Limitations and Recommendations for Future Research

While the study provides significant insights into the relationship between digitalization and export diversification, several limitations warrant further investigation. First, although this study employs macroeconomic indicators, such as internet usage and e-government, to measure digitalization, these proxies may not fully capture the complexity of digital adoption at the sectoral or regional levels. Given the abundance of firm-level studies in existing literature, future research could bridge the gap by integrating both macro- and micro-level data to explore how firm-level digital strategies complement national digitalization efforts in driving export diversification.

Second, the analysis revealed distinct patterns of digitalization's impact across income groups and product categories, such as the tipping-point effect of internet usage in low-income countries. However, the structural and institutional factors influencing these thresholds remain insufficiently explored. Future studies could investigate how regional trade agreements, industrial policies, and market liberalization interact with digitalization to enable low-income countries to overcome structural barriers and achieve diversification benefits.

Lastly, the heterogeneity analysis for ParVEM found no statistically significant effects of digitalization variables across product categories, which may indicate that partner diversification depends more on factors such as supply chain integration, logistical efficiency, and sector-specific trade policies. Future studies could delve into these alternative drivers and examine how sector-specific digital strategies, such as digital trade platforms or blockchain-enabled supply chains, impact partner diversification.

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Appendix

Table 12. HS Code and WCO Classification Match Table

WCO Section	HS 2-Digit	Description	Tech Level
1	1-5	LIVE ANIMALS; ANIMAL PRODUCTS	Non
2	6-14	VEGETABLE PRODUCTS	Non
3	15	ANIMAL OR VEGETABLE FATS AND OILS AND THEIR CLEAVAGE PRODUCTS; PREPARED EDIBLE FACTS; ANIMALS OR VEGETABLE WAXEES	Non
4	16-24	PREPARED FOODSTUFFS; BEVERAGES, SPIRITS AND VINEGAR; TOBACCO AND MANUFACTURED TOBACCO SUBSTITUTES; PRODUCTS, WHETHER OR NOT CONTAINING NICOTINE, INTENDED FOR INHALATION WITHOUT COMBUSTION; OTHER NICOTINE CONTAINING PRODUCTS INTENDED FOR THE INTAKE OF NICOTINE INTO THE HUMAN BODY	Non
5	25-27	MINERAL PRODUCTS	Non
6	28-38	PRODUCTS OF THE CHEMICALOR ALLIED INDUSTRIES	Med
7	39-40	PLASTICS AND ARTICLES THEREOF; RUBBER AND ARTICLES THEREOF	Low
8	41-43	RAW HIDES AND SKINS, LEATHER, FURSKINS AND ARTICLES THEREOF; SADDLERY AND HARNESS; TRAVEL GOODS, HANDBAGS AND SIMILAR CONTAINERS; ARTICLES OF ANIMAL GUT (OTHER THAN SILK-WORM GUT)	Low
9	44-46	WOOD AND ARTICLES OF WOOD; WOOD CHARCOAL; CORK AND ARTICLES OF CORK; MANUFACTURES OF STRAW, OF ESPARTO OR OF OTHER PLAITING MATERIALS; BASKETWARE AND WICKERWORK	Low

10	47-49	PULP OF WOOD OR OF OTHER FIBROUS CELLULOSIC MATERIAL; RECOVERED (WASTE AND SCRAP) PAPER OR PAPERBOARD; PAPER AND PAPERBOARD AND ARTICLES THEREOF	Low
11	50-63	TEXTILES AND TEXTILE ARTICLES	Low
12	64-67	FOOTWEAR, HEADGEAR, UMBRELLAS, SUN-UMBRELLAS, WALKING-STICKS, SEAT-STICKS, WHIPS, RIDING-CROPS AND PARTS THEREOF; PREPARED FEATHERS AND ARTICLES MADE THEREWITH; ARTIFICIAL FLOWERS; ARTICLES OF HUMAN HAIR	Low
13	68-70	ARTICLES OF STONE, PLASTER, CEMENT, ASBESTOS, MICA OR SIMILAR MATERIALS; CERAMIC PRODUCTS; GLASS AND GLASSWARE	Low
14	71	NATURAL OR CULTURED PEARLS, PRECIOUS OR SEMI-PRECIOUS STONES, PRECIOUS METALS, METALS CLAD WITH PRECIOUS METAL, AND ARTICLES THEREOF; IMITATION JEWELLERY; COIN	Med
15	72-83	BASE METALS AND ARTICLES OF BASE METAL	Med
16	84-85	MACHINERY AND MECHANICAL APPLIANCES; ELECTRICAL EQUIPMENT; PARTS THEREOF; SOUND RECORDERS AND REPRODUCERS, AND TELEVISION IMAGE AND SOUND RECORDERS AND REPRODUCERS, AND PARTS AND ACCESSORIES OF SUCH ARTICLES	High
17	86-89	VEHICLES, AIRCRAFT, VESSELS AND ASSOCIATED TRANSPORT EQUIPMENT	High
18	90-92	OPTICAL, PHOTOGRAPHIC, CINEMATOGRAPHIC, MEASURING, CHECKING, PRECISION, MEDICAL OR SURGICAL INSTRUMENTS AND APPARATUS; CLOCKS AND WATCHES;	High

		MUSICAL INSTRUMENTS; PARTS AND ACCESSORIES THEREOF	
19	93	ARMS AND AMMUNITION; PARTS AND ACCESSORIES THEREOF	Med
20	94-96	MISCELLANEOUS MANUFACTURED ARTICLES	Low
21	97	WORKS OF ART, COLLECTORS' PIECES AND ANTIQUES	Non

국문 초록

본 연구는 디지털화가 수출 다각화에 미치는 영향을 두 가지 차원—수출 상품 다양도 (ProVEM)와 수출 시장(교역 상대국) 다양도 (ParVEM)—에서 분석하였다. 주요 디지털 변수인 인터넷 사용률과 전자정부가 국가의 소득 수준과 무역 환경에 따라 수출 다각화를 어떻게 촉진하는지 평가하였다.

수출 상품 다양도 (ProVEM) 분석 결과, 인터넷 사용은 수출 상품 다양도를 촉진하는 주요 요인으로 나타났으며, 특히 고소득 국가에서 고도화된 디지털 인프라와 제도적 역량으로 인해 그 효과가 두드러졌다. 전자정부는 무역장벽을 줄이고 거버넌스를 개선하여 모든 제품 카테고리에서 수출 상품 다양도를 촉진하였다. 저소득 국가의 경우, 인터넷 연결성이 일정 임계치를 초과한 이후에 디지털화의 효과가 두드러지게 나타났다.

교역 상대국 다양도 (ParVEM)의 경우, 인터넷 사용이 고소득 국가에서 교역 상대국 다양도를 유의미하게 촉진하는 것으로 확인되었으며, 전자정부는 점진적인 긍정적 효과를 보여주며 거버넌스 개혁이 시간이 지나며 무역에 실질적인 영향을 미친다는 점을 시사하였다. 저소득 국가에서는 디지털화가 기본적인 디지털 연결성 임계치에 도달하기 전까지는 교역 상대국 다양화에 제한적인 영향을 미쳤다. 이는 디지털 인프라 투자와 보완적 정책이 이러한 국가에서 중요한 역할을 함을 보여준다.

본 연구는 소득 수준과 무역 환경에 따라 맞춤형 디지털화 전략이 필요하다는 점을 강조한다. 디지털 인프라 및 거버넌스 개혁은 디지털화의 혜택을 극대화하고, 수출 다각화를 효과적으로 지원하기 위한 핵심 요소로 작용할 것이다.