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Department of Economics
SOAS University of London
Thornhaugh Street, Russell Square, London WC1H 0XG, UK
Phone: + 44 (0)20 7898 4730
Fax: 020 7898 4759
E-mail: economics@soas.ac.uk
http://www.soas.ac.uk/economics/

Unveiling Structure and Dynamics of Global Digital Production Technology Networks: A new digital technology classification and network analysis based on trade data

Antonio Andreoni[1], Guendalina Anzolin[2], Mateus Labrunie[3], Danilo Spinola[4]

Abstract

This research pioneers the construction of a novel Digital Production Technology Classification (DPTC) based on the latest Harmonised Commodity Description and Coding System (HS2017) of the World Customs Organisation. The DPTC enables the identification and comprehensive analysis of 127 tradable products associated with digital production technologies (DPTs). The development of this classification offers a substantial contribution to empirical research and policy analysis. It enables an extensive exploration of international trade in DPTs, such as the identification of emerging trade networks comprising final goods, intermediate components, and instrumentation technologies and the intricate regional and geopolitical dynamics related to DPTs. In this paper, we deploy our DPTC within a network analysis methodological framework to analyse countries' engagements with DPTs through bilateral and multilateral trade. By comparing the trade networks in DPTs in 2012 and 2019, we unveil dramatic shifts in the global DPTs' network structure, different countries' roles, and their degree of centrality. Notably, our findings shed light on China's expanding role and the changing trade patterns of the USA in the digital technology realm. The analysis also brings to the fore the increasing significance of Southeast Asian countries, revealing the emergence of a regional hub within this area, characterised by dense bilateral networks in DPTs. Furthermore, our study points to the fragmented network structures in Europe and the bilateral dependencies that developed there. Being the first systematic DPTC, also deployed within a network analysis framework, we expect the classification to become an indispensable tool for researchers, policymakers, and stakeholders engaged in research on digitalisation and digital industrial policy.

Keywords: Digital Production Technology (DPT), DPT Classification, Network Analysis, Bilateral Trade, Digitalisation patterns.

JEL classification: O14, O33, F14

[1] Department of Economics, SOAS University of London & South African Research Chair in Industrial Development, University of Johannesburg. aa155@soas.ac.uk
[2] Centre for Science, Technology and Innovation Policy, Institute for Manufacturing, University of Cambridge. gma39@cam.ac.uk
[3] Centre of Development Studies and Cambridge Industrial Innovation Policy, University of Cambridge. mateus.labrunie@gmail.com
[4] College of Accounting, Finance and Economics, Birmingham City Business School; Maastricht Economic Research Institute for Innovation and Technology (UNU-Merit); and South African Research Chair in Industrial Development, University of Johannesburg. danilo.spinola@bcu.ac.uk

1. Introduction

The development, production, and diffusion of Digital Production Technologies (DPTs) are increasingly altering the nature of manufacturing production while blurring the boundaries between the physical and digital realms. In manufacturing, 'digitalisation' is more specifically applied to transforming productive activities and tasks into digital formats. That includes manufacturing systems and the closely associated digital infrastructures supporting these activities. From this perspective, digitalisation relates to the production, adoption, and diffusion of Digital Production Technologies (DPTs), including (i) Artificial Intelligence and data analytics, (ii) Smart robotics and additive manufacturing, and (iii) Internet of Things (IoT), cloud computing, and network technologies. In the industrial sector, various technology clusters are integrated into systems composed of highly complementary sub-systems and technologies (Sturgeon, 2021).

There have been various attempts to capture the extent to which countries have advanced in their industrial digitalisation and readiness. Nonetheless, we observe a minor emphasis on measuring and understanding how digitalisation contributes to forming new digital production trade technology networks. These networks connect countries and regions, creating new global structures and influencing technology production, adoption, and diffusion dynamics. This paper addresses the gap in measuring digitalisation by developing a new *Digital Production Technology Classification* (DPTC) comprising 127 tradable physical products, each identified in the latest 6-digit Harmonised Commodity Description and Coding System (HS2017) of the World Customs Organisation. We cluster the selected products into three main groups: *final digital technologies*, *components of digital technologies*, and *instrumentation for digital technologies.* This approach aims to differentiate various tradable products, which are characterised by different levels of production complexity and functions. We then apply this novel tool to reveal the developing networks of final and intermediate components of DPTs, concentrating on the bilateral trade patterns of countries and regions.

Our research makes a two-fold contribution to the existing body of literature. First, it introduces a new DPTC whereby evidence on digitalisation can be generated in a more structured and comprehensive way, beyond an *ad-hoc* and partial list of products used in the literature. At a time of increasing trade tensions around key digital technologies (e.g., semiconductors), a systematic categorisation and analysis of DPTs is critical to understanding the evolving global industrial landscape and underlying global value chains. Second, by adopting our DPTC within a network analysis methodological framework, our study provides an in-depth analysis of global digital technology networks' structure and changing patterns. We focus on two data points, 2012 and 2019, and conduct a comparative analysis of the two DPTs network structures. Through this comparative analysis, we can identify and examine key trends, shifts, and developments in the global landscape of digital production technology.[1] Notably, our findings shed light on China's expanding role and the changing trade patterns of the USA in the digital technology realm. The analysis also brings to the fore the increasing significance of Southeast Asian countries, revealing the emergence of a regional hub within this area, characterised by dense bilateral networks in DPTs. Furthermore, our study points to the fragmented network structures in Europe and the bilateral dependencies that developed there.

The remainder of the paper is structured as follows. In Section 2, we delve into the existing literature on the subject. Section 3 lays out the analytical framework that guides our study, while Section 4 details the methodology employed for our classification. The descriptive analysis is presented in Section 5, followed by a comprehensive network analysis in Section 6. Finally, Section 7 wraps up our study, drawing conclusions based on our research.

2. Literature review

2.1 Industrial digitalisation and existing attempts to measure it

Industrial digitalisation is now a major trend, with many governments and international organisations investigating its potential, advantages and current diffusion. Many recent works have sought to measure a country's "readiness" for or degrees of engagement with digital technologies. This evaluation is typically done through *industrial surveys, readiness indices,* and *international trade analysis*.

[1] Our analysis primarily targets tradable physical products, not fully capturing the trade in digital services, a key value driver in digital technologies. Due to sparse data on digital service trade, we couldn't systematically include it in our global bilateral trade flow study. However, by focusing on countries' use of digital production technology in manufacturing, we indirectly touch upon aspects of digital service trade. Tradable DPTs often serve as channels for such services, a trait common in advanced manufacturing technologies linked with high-end technology and business services.

Industrial surveys centred on digitalisation have predominantly focused on advanced economies and a select number of middle-income countries. Surveys in advanced countries include the European Manufacturing Survey[1] (Albrieu et al. 2019), the European Investment Bank Investment Surveys (EIBIS), studies from Yu (2018) for South Korea, Sommer (2015) for Germany, and research by Frank et al. (2019), along with EIB (2021) for the EU region[2]. Surveys in middle-income countries have involved countries like Argentina, Brazil, Vietnam, Thailand and Ghana, see reports from UNIDO (2019) as well as UNDP (2020); also, more in-depth country-specific analyses have focused on Brazil (Ferraz et al., 2019) and South Africa (Andreoni et al., 2023) to reveal extensive details on the adoption of DPTs and their deployment in different functional areas of production, management, etc. However, distinct methodologies and data variations often limit their international comparability.

Secondly, country-level indexes offer the advantage of international comparability, enabling a benchmarking of countries' readiness and performance in various digitalisation areas, such as connectivity, technology absorption, and skills. However, they fall short of capturing how much countries adopt or engage with DPTs, limiting themselves to capturing a country's loosely defined 'readiness' for digital technologies. That implies that they rely on indirect measures based on existing country-level data regarding infrastructure, institutions, innovation, and production, which are presumed to be associated with DPTs. These methods frequently exhibit significant limitations, such as conflating various types and qualities of measures and data. They frequently become composites of composite indexes, applying arbitrary weights to each constituent factor. Consequently, interpreting these indexes and their related country rankings becomes difficult, often masking important distinctions and developing trends. Table 1 below outlines various existing digital-technology-related indexes and highlights their limitations.

More aligned with our paper's approach, a UNIDO study encompassing 167 countries offers a country-level digitalisation analysis using robust indicators such as

[1] The European Manufacturing Survey (EMS) aims to map the innovativeness of the manufacturing industry in various European countries and beyond. Every three years, data on technological and organizational innovations in manufacturing and related improvements in performance in the manufacturing industry in more than 12 European countries are collected. The last survey was conducted in December 2022. https://www.isi.fraunhofer.de/en/themen/wertschoepfung/fems.html#367861728

[2] https://www.eib.org/en/publications/digitalisation-in-europe-2020-2021.

patent family applications, international trade, and imports of advanced digital production technologies (UNIDO, 2020). Additionally, recent research has expanded the sample of countries from UNIDO, employing export data (from UN Comtrade) to evaluate the revealed comparative advantage in capital and Industry 4.0 goods, as well as robot intensity and employment risk indicators (Macedo et al., 2020). In both studies, the examination of tradable products focuses on a narrow range of prominent technologies from the HS list. This is a limited and arbitrary list of products, presenting several limitations for systematic analysis.

Castellani et al. (2022) implemented a more systematic strategy in developing a new classification of international trade product codes to measure the adoption of 'Industry 4.0' technologies. Their classification emerges from an iterative process and has been subject to various sensitivity analyses. The classification is based on the EU trade classification and is limited to European countries. Because this classification is tailored to the EU, it cannot be deployed to conduct analyses involving all countries. To the best of our knowledge, comprehensive classification spans the entire global economy. That opens a research gap we aim to fill with this research.

Our research extends these prior contributions and aims to address two notable gaps and methodological limitations. Firstly, we employ systematic methods and multiple sensitivity tests to establish a robust DPT Classification. This new classification adopts a detailed and triangulated approach for identifying products as DPTs. Secondly, we combine our innovative DPT Classification with network analysis techniques to understand the structure and dynamics of countries' involvement with DPTs – an endeavour we believe has not yet been undertaken.

Table 1. Overview of Global Digital Technology Indexes: Descriptions and Limitations

	Description	***Limitations***
WEF Global Competitiveness Index 4.0 (2019)	*The aggregate of 103 individual indicators is organised into 12 pillars: institutions, infrastructure, ICT adoption, macroeconomic stability, health, skills, product market, labour market, financial system, market size, business dynamism, and innovation capability.*	*A composite index uses indicators of different natures (hard quantitative data and survey data) and even composite indexes, making it a composite of composite indexes with arbitrary weights attributed to each indicator.*
WEF Readiness for the Future of Production (2018)	*The composite index of 59 indicators seeking to capture the "future of production capabilities" based on "structure of production" and 'drivers of production' indicators*	*A composite index uses indicators of different natures (hard quantitative data and survey data) and even composite indexes, making it a composite of composite indexes with arbitrary weights attributed to each indicator.*
UNCTAD Readiness for Frontier Technologies Index (2021)	*A composite index of 9 indicators in 5 dimensions: ICT deployment, skills, R&D activity, industry activity, and access to finance. Weights attributed using principal component analysis.*	*Composite index.*
World Bank Digital Adoption Index (2016)	*The composite index is calculated as the average of three sub-indexes measuring countries' digital adoption across three dimensions of the economy: business (4 indicators), people (2 indicators), and government (3 indicators).*	*Composite index using indicators of different natures (hard quantitative data, and survey data), and even composite indexes, making it a composite of composite indexes, with arbitrary weights attributed to each indicator.*
ITU ICT Development Index (2017)	*A composite index of 11 indicators is used to monitor and compare developments in ICTs across three dimensions: ICT access, ICT use, and ICT skills.*	*They are focused solely on ICTs. Composite index using indicators of different natures (hard quantitative and survey data), with arbitrary weights attributed to each indicator.*
WIPO Global Innovation Index (2021)	*A composite index of 81 indicators across seven dimensions: Institutions, Human capital and research, Infrastructure, Market sophistication, Business sophistication, Knowledge and technology outputs, Creative outputs*	*Composite index using indicators of different natures (hard quantitative data, and survey data), and even composite indexes, making it a composite of composite indexes, with arbitrary weights attributed to each indicator.*
Vereinte (2020)	*Composite index of 10 indicators across three dimensions of e-government: provision of online services, telecommunication infrastructure, and human capital*	*They are focused solely on government. Composite index using indicators of different natures (hard quantitative and survey data), with arbitrary weights attributed to each indicator.*
Portulans Institute's Network Readiness Index (2021)	*A composite index of 60 indicators across four dimensions: technology, people, governance, and impact.*	*The nebulous concept of 'Network readiness'. A composite index uses indicators of different natures (hard quantitative data and survey data) and even composite indexes, making it a composite of composite indexes with arbitrary weights attributed to each indicator.*
Economist Impact's The Inclusive Internet Index (2021)	*A composite index of 62 indicators across four dimensions and 24 background indicators. The four dimensions are Availability, Affordability, Relevance, and Readiness. The weights of each indicator were discussed with experts.*	*Composite index using indicators of different natures (hard quantitative and survey data).*
ITU Global Cybersecurity Index (2020)	*A composite index of 20 indicators across five dimensions of cybersecurity: Legal measures, technical measures, organisational measures, capacity development, and cooperation. Data was obtained through a questionnaire. The weights of each indicator are discussed with a panel of experts.*	*Composite index.*
Huawei's Global Connectivity Index (2020)	*A composite index of 40 indicators tracking the impact of ICTs on a nation's economy, digital competitiveness and future growth. The indicators can be grouped 'vertically' (supply, demand, experience, and potential) and horizontally (broadband, cloud, IoT, and AI).*	*Composite index with arbitrary weights.*
Speedtest Global Index (July 2022)	*An index measuring the median download speed of mobile and fixed broadband reflects the speeds a user is likely to achieve in a country.*	*Index limited to internet speed.*
IMD World Digital Competitiveness Ranking (2021)	*A composite index of 52 indicators tracks how countries adopt and explore digital technologies across three dimensions: knowledge, technology, and future readiness.*	*Composite index using indicators, including composite indexes, makes it a composite of composite indexes, with arbitrary weights attributed to each indicator.*

Source: Labrunie (2024).

3. Analytical framework underpinning our new DPT Classification

In the analysis of digitalisation, our focus on production technologies stems from the pivotal role of manufacturing as the backbone of contemporary economies (Kaldor, 1966; Szirmai, 2015; Andreoni and Chang, 2016) and the special role of capital goods in the industrialisation process (Rosenberg, 1963; Amsden and Chu, 2003; Andreoni and Chang, 2019). That includes creating high-paying jobs, a substantial proportion of which are in crucial research and development activities, promoting high spillover to the rest of the economy and driving significant demand for high-tech support services from other sectors (Tassey, 2014). Furthermore, production technologies – particularly digital – are increasingly considered key drivers of productivity within the manufacturing sector and beyond (Andreoni and Anzolin, 2019; Sturgeon, 2021; Andreoni et al., 2021).

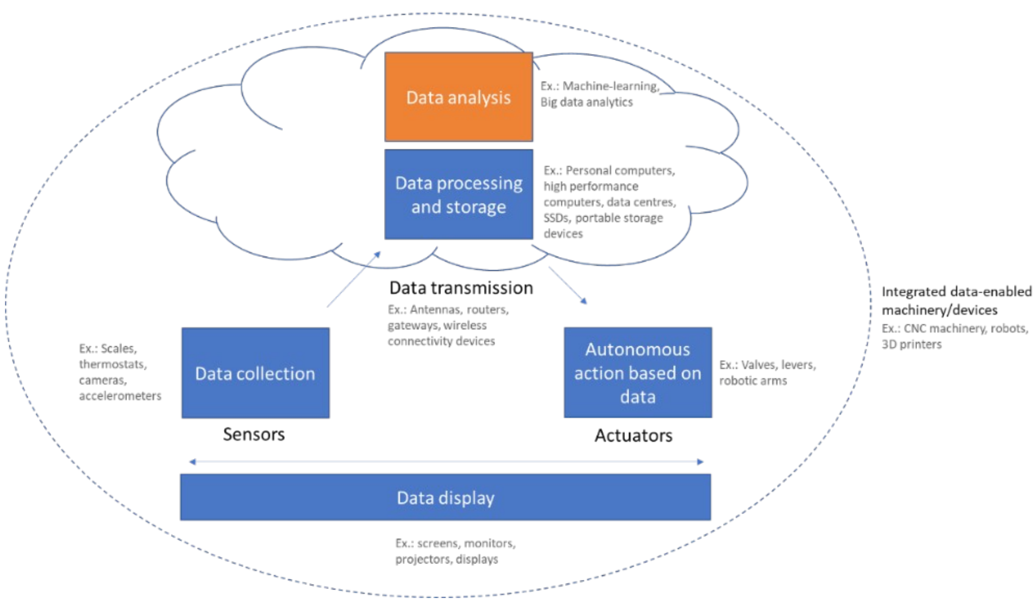
In this context, production digitalisation is the process of acquiring, collecting, and analysing data within the production system, encompassing activities within a firm and along the entire value chain. The sensorisation of the production system and diffusion of IIoT allows data to be constantly generated from any production-related activity, including activities integrating smart robotics and additive manufacturing. Data analytics, machine learning, and AI-enabled by cloud computing and network technologies can provide feedback to the production system with optimised decisions, forecasts and solutions.

Our DPTC focuses on production technologies that are required for the digitalisation of a production system and are traded in the international markets as different types of products. Specifically, we build on a standard distinction between final capital goods and parts (i.e., intermediate components) and consider instrumentation technologies, also known as 'infra-technologies', used for measuring, calibrating, and standardising processes (see Tassey et al., 2009). These different products allow complex, increasingly computer-controlled, and integrated systems to operate, generate, collect, and analyse data (Tassey, 2009 and 2014).

Most production technologies have digital potential; they can be made part of these systems through sensorisation and connectivity. The complexity of production technologies with digital potential lies in the interrelated evolution between physical attributes and connectivity efficiency, shifting the competitive edge of high-tech products. Even automation, which is often a pre-condition of a fully digitalised process, is a necessary yet non-sufficient condition to embark on digital production technologies that require a complex set of hardware and software technologies, whose interdependence is at the core of the combinations between digital production equipment and final digital product characteristics (Ardolino et al., 2018).

One of the critical elements of the digitalisation process – and the cornerstone for our classification – is data collection, storage and analysis. In line with this, we developed a simple framework (Figure 1), which focuses on technologies that facilitate control optimisation and data collection and analysis (see also Abosata et al. 2021).

Figure 1. Production Digitalisation and Data Structure



Source: Authors

Sensors are one of the key technologies for data collection and management; they allow the creation of different streams of data into unified business systems within firms; for example, data integration enables the connection of Manufacturing Execution System, Enterprise Resource Planning, and other database management, thus enabling data transmission across production flows and – increasingly – supply chain (Colombari et al. 2023). Our classification gives special attention to various types of sensors, including thermostats, scales, cameras, and accelerometers (vibration sensors). Sensors are a critical component of advanced manufacturing (PCAST, 2011); they allow the generation of data that is then transmitted through devices such as antennas, gateways, routers, and other wired or wireless connectivity devices. The transmitted data is then processed, analysed, and stored in the firm's or cloud computing providers' systems. Data processing requires computers (personal or high-performance), and data storage requires SSDs or other storage devices. Data analysis, traditionally performed by human technicians using conventional software, is increasingly handled by automated data analytics algorithms, including machine learning and its variants. The analysed data is then returned to the shopfloor (or, in many cases, has never left) and can either provide insights for decision-making by humans or generate autonomous responses, such as closing a valve, moving a lever, activating a cooling system, opening a hatch or window, ordering a spare part, etc. – all without human interference. Devices that are made explicitly for this purpose are named actuators. Furthermore, in every step of this process, data must be displayed for setting up, monitoring, tracking, and maintenance purposes. In our classification, we only incorporated products that fall under one or more of the following functions in digital production processes: data collection, data transmission, data processing, data storage, data display, actuators, or integrated data-enabled machines/devices.

4. Methodology for the classification and network analysis

Building on our understanding of different technologies involved in the digitalisation of production, as discussed in section 3, we devised an empirical approach and methodology to identify the relevant technologies as different types of products reported in the trade data at six digits, hence, with a granular level of specification. We then conduct several types of sensitivity analyses to test our new classification.

The creation of our Digital Production Technology (DPT) Classification involves several methodological steps, which we detail below:

Step 1: Data selection and levels of product classification

We begin our analysis by extracting trade data at the six-digit level. This level of detail is crucial as it highlights key product characteristics that enabled us to classify them as DPTs. While there are some caveats in using trade data[1], it is still the most reliable data source, with granular data available for most countries. The main caveat is that trade data does not capture products that are produced and consumed in the domestic economy. Hence, it is biased, especially for those economies with a large internal market and domestic-oriented manufacturers of digital technologies. As discussed in note 1, trade in services are not included here, given data limitations.

Step 2: Selection of the most suitable product classification

In the next step, we employ the latest product classification system, the Harmonized System (HS) 2017. This choice is particularly relevant for our study because the HS 2017 includes new product codes that are specifically designed to categorise products based on their digital attributes. For instance, this classification system provides distinct codes for machines based on their internet connectivity capabilities, differentiating between those that can connect to the internet and those that cannot. This level of detail in product classification is crucial for our analysis, as it allows for a more accurate and nuanced identification of digital production technologies.

Step 3: Identification of the relevant HS Chapters and BECs filtering criteria

To identify DPTs (i.e., capital goods, parts, and instrumentation), we narrowed our research to specific product categories (clustered within so-called Chapters) within the HS 2017 classification. We selected the following chapters, given our focus on production technologies:

- HS 2017 Chapter 84 includes machinery and mechanical appliances and their parts.

[1] The main limitation is it being restricted to hardware, when increasingly the higher value-added segments of production are the knowledge-intensive services such as software development and implementation, R&D, design, marketing, and post-sale activities. Other problems with trade data include: 1. Not accounting for the fact that some countries might produce many of the products internally, and thus not appear in trade data; 2. Not being able to capture which activities were actually done in the country, and thus how much value was actually added in the country; 3. Not differentiating trade carried out by MNCs or local firms.

- HS 2017 Chapter 85 includes electrical machinery and equipment, sound recorders and reproducers, television image and sound recorders and reproducers, and parts and accessories of such articles.
- HS 2017 Chapter 90 covers optical, photographic, cinematographic, measuring, checking, precision instruments and apparatus, along with their parts and accessories.

Additionally, to ensure our analysis remains focused on machinery and appliances used in digital manufacturing production and excludes those intended for consumer use, we filtered these three HS chapters using the Broad Economic Categories 4 (BEC 4) classification:

- BEC 4 Chapter 41, which is dedicated to capital goods, excluding transport equipment.
- BEC 4 Chapter 42, which covers parts and accessories.
- BEC 4 Chapter 22, which includes industrial supplies not specified elsewhere and that have been processed.

By applying these three filtering criteria to our products clustered under HS 84, 85 and 90, we narrowed the list of potential DPTs to 818 products. This subgroup of HS products is particularly relevant for our research as it encompasses products central to digital manufacturing production; however, this group might include potentially digital products that are still not specifically related to the digitalisation of production.

Step 4: Systematic identification of DPTs through keyword selection and product analysis

From the comprehensive list of products with digital potential, we distinguish those that we can clearly identify as digital production technologies based on their detailed 'self-explanatory description' and related keywords. Specifically, we start with the 818 products selected from HS 2017 Chapters 84, 85, and 90, intersecting with BECS 4 Chapters 41, 42, and 22. Among them, we then select keywords and verify their presence in the 'self-explanatory description' of each 6-digit product code. We tested multiple keywords automatically and assessed their outcomes; we interrogated the data set by reiterating the keyword identification process until saturation, that is, until no further products were found. The selected keywords for which we could find correspondence in the 'self-explanatory description' were:

- (E)lectronic, (D)ata, (N)umerical, (N)etwork, (A)utomatic, (T)ransistor, (S)emiconductor, (I)nstruments, (A)pparatus, (W)afers, (C)alcul-, (C)ontrol, (T)esting, (M)eter, (R)emote, (-)stats, (R)adio, (W)eigh.[2]

Implementing the filters mentioned earlier significantly streamlined our dataset, narrowing the product count from the original 818 to 262 products. To ensure our study's accuracy and reliability, we reviewed each of these 262 products. This review process involved meticulously examining each product in consultation with experts to assess its connection to digitalisation. Products that were not directly related to digitalisation were excluded from the classification.[3]

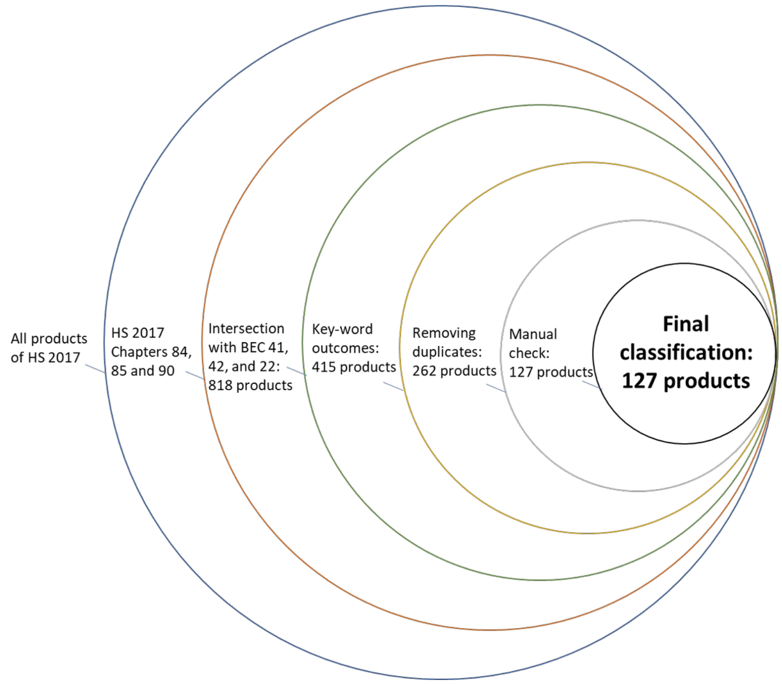
As a result of this rigorous vetting process, we identified a final list of 127 products. These products are DPTs; they are either final capital goods, parts or instrumentations closely related to the digitalisation of production. We have included a complete list of these 127 products in Annexe I. Alongside each product, we have detailed the rationale behind its inclusion, offering insights into the specific factors determining its relevance to digitalisation within our study.

For a concise overview of our methodological approach, please see Figure 2. This figure summarises the steps we took in refining our product list, from the initial application of filters to the final manual check and selection of products. This visual representation is intended to provide a clear and straightforward understanding of our methodology, outlining the process that led us to identify the 127 products most pertinent to our study of digitalisation.

Figure 2. Summary of the methodological steps to build the DPT Classification

[2] Other keywords were tried but excluded as their results were either void, redundant, or misleading. These included: wireless, artificial, computer, automated, sensors, printer, digital, chips, conductor, additive, internet.

[3] Some products had the key words but not with the intended meaning. For example, many products had the word ‘numerical’ in the expression ‘not numerically controlled’, thus being exactly the opposite of what we were trying to capture. Another example: Product code 844711 ‘Circular knitting machines, with cylinder diameter <= 165 mm’ has the word ‘meter’ within ‘diameter’ which is completely unrelated to what we wanted to capture with the keyword ‘meter’ – aimed at thermometers, electrical current meters, and other sensors. Also, all medical devices were excluded from the analysis.



Source: Authors

4.2 Sensitivity analysis on the distribution of selected products

Based on the DPTC derived, we conduct two levels of sensitivity analysis – product and country levels – to reveal potential biases, as well as the composition and distribution of identified products in trade and across countries.

Sensitivity 1. Products

Analysing the trade data for the 127 products in our classification reveals several insights. Firstly, these products play a significant role in global trade, comprising 14.0% of the total traded value worldwide. Secondly, a sensitivity analysis of our classification shows a concentration in the value of digital products: 17 products make up 80% of the global digital trade, and 32 products account for 90% of it, as detailed in Table 2 below.

From Table 2, the products that dominate the classification of traded value are electronic integrated circuits (of many different types) and the machinery and parts used for their production, telephones for cellular networks and other communication apparatus, and portable data processing machines and their components. That reinforces the argument made by some authors (Andreoni et al., 2021) that digitalisation is an 'evolutionary revolution'; that is, it is highly dependent on its microelectronic base and thus is a continuation of the so-called Third Industrial Revolution rather than a Fourth one.

Table 2. Products Constituting 80% of Global Digital Trade in 2018

H5 – 6 digit commodity code	**Product name**	**Trade value in Bl US$**	***% of digital trade***	***Cumulative % of digital trade***	***Cumulative % of total trade***
	Global total trade	18,116.38	-	-	100%
	Global digital trade	2,538.88	100%	100%	14.0%
854231	Electronic integrated circuits as processors and controllers, whether or not combined with memories, converters, logic circuits, amplifiers, clock and timing circuits, or other circuits	301.91	11.9%	11.9%	1.67%
851712	Telephones for cellular networks, "mobile telephones" or other wireless networks	270.40	10.7%	22.5%	3.16%
854239	Electronic integrated circuits (excl. such as processors, controllers, memories and amplifiers)	252.86	10.0%	32.5%	4.55%
854232	Electronic integrated circuits as memories	231.32	9.1%	41.6%	5.83%
851762	Machines for the reception, conversion and transmission or regeneration of voice, images or other data, incl. switching and routing apparatus (excl. telephone sets, telephones for cellular networks or other wireless networks)	161.33	6.4%	48.0%	6.72%
847130	Data-processing machines, automatic, portable, weighing <= 10 kg, consisting of at least a central processing unit, a keyboard and a display (excl. peripheral units)	139.21	5.5%	53.5%	7.49%
851770	Parts of telephone sets, telephones for cellular networks or other wireless networks and other apparatus for transmitting or receiving voice, images or other data, n.e.s.	133.92	5.3%	58.7%	8.23%
847330	Parts and accessories of automatic data-processing machines or for other machines of heading 8471, n.e.s.	122.67	4.8%	63.6%	8.91%
847150	Processing units for automatic data-processing machines, whether or not containing in the same housing one or two of the following types of unit: storage units, input units, output units (excl. those of heading 8471.41 or 8471.49 and excl. peripheral units)	80.17	3.2%	66.7%	9.35%
847170	Storage units for automatic data-processing machines	77.34	3.0%	69.8%	9.78%
852990	Parts suitable for use solely or principally with transmission and reception apparatus for radio-broadcasting or television, television cameras, digital cameras, video camera recorders, radar apparatus, radio navigational aid apparatus or radio remote control apparatus, monitors and projectors, n.e.s. (excl. for aerials and aerial reflectors of all kinds)	55.19	2.2%	71.9%	10.08%
854140	Photosensitive semiconductor devices, incl. photovoltaic cells, whether or not assembled in modules or made up into panels; light emitting diodes (excl. photovoltaic generators)	50.10	2.0%	73.9%	10.36%
848620	Machines and apparatus for the manufacture of semiconductor devices or of electronic integrated circuits	43.90	1.7%	75.6%	10.60%
901380	Liquid crystal devices, n.e.s. and other optical appliances and instruments not elsewhere specified in chapter 90	42.28	1.7%	77.3%	10.83%
852351	Solid-state, non-volatile data storage devices for recording data from an external source [flash memory cards or flash electronic storage cards] (excl. goods of chapter 37)	32.90	1.3%	78.6%	11.01%
848690	Parts and accessories for machines and apparatus of a kind used solely or principally for the manufacture of semiconductor boules or wafers, semiconductor devices, electronic integrated circuits or flat panel displays, and for machines and apparatus specified in note 9 C to chapter 84, n.e.s.	26.11	1.0%	79.6%	11.16%
903289	Regulating or controlling instruments and apparatus (excl. hydraulic or pneumatic, manostats, thermostats, and taps, cocks and valves of heading 8481)	24.69	1.0%	80.6%	11.30%

Source: Authors

Sensitivity 2: Countries

In the context of digital imports, trade distribution across countries shows a concentration pattern, though it is marginally less pronounced compared to other sectors. An analysis of the data reveals that 14 countries account for 80% of the global digital imports. Expanding this scope slightly further, 23 countries comprise 90% of the total digital imports worldwide. That indicates a significant level of trade concentration in a relatively small group of countries (China, Taiwan, and Rep. of Korea). However, the distribution is somewhat more dispersed than in other sectors.

Table 3. Country shares in digital exports, representing 90% of global digital exports

	Country	**% of global digital exports**	**Cumulative % of global digital exports**
1	China	32.9	32.9
2	Taiwan	11.4	44.3
3	Rep. of Korea	7.9	52.1
4	USA	5.6	57.7
5	Malaysia	5.5	63.2
6	Japan	5.4	68.6
7	Viet Nam	4.8	73.4
8	Germany	3.6	77.0
9	Singapore	3.2	80.1
10	Mexico	2.6	82.8
11	Netherlands	2.5	85.3
12	Thailand	2.4	87.6
13	Philippines	1.9	89.5
14	United Kingdom	1.0	90.5

Source: Authors

The data in Table 3 reveals significant insights into the global distribution of digital exports. China's dominance in this sector is evident, as it accounts for nearly a third (32.9%) of global digital exports, highlighting its pivotal role in the digital economy. This significant share indicates China's substantial influence and capacity in the digital market, possibly due to its large manufacturing base and advanced technological infrastructure.

Following China, Taiwan and the Republic of Korea comprise a considerable portion of the market, with 11.4% and 7.9% respectively. Taiwan's strong performance could be attributed to its advanced semiconductor industry, which is crucial for digital products.

Similarly, Korea's notable share reflects its well-established electronics and technology sectors.

The United States, though fourth in the ranking, contributes 5.6% to global digital exports. This percentage, while smaller relative to China, is still significant given the global scope of the market. The US's contribution likely stems from its leading role in software and technology services.

Other notable contributors include Malaysia, Japan, and Vietnam, each with over 4% of global shares, underscoring the importance of the Asia-Pacific region in the digital export landscape. As the leading European country in this list, Germany represents Europe's significant role in the global digital market.

The cumulative percentages illustrate how these countries collectively shape the digital export market. By the time the list reaches the United Kingdom at 14th place, these countries together account for over 90% of global digital exports. This concentration suggests a highly competitive and concentrated market, with a few key players dominating a large portion of global exports.

In summary, this data highlights the geopolitical landscape of digital exports, showing a strong Asian presence led by China, Taiwan, and Korea, along with significant contributions from the United States and key European nations like Germany and the Netherlands. Understanding these dynamics is crucial for analysing global trade patterns and the digital economy's future trends.

Table 4. Country shares in digital imports, representing 90% of global digital imports

	Country	**% of global digital imports**	**Cumulative % of global digital imports**
1	China	21.3	21.3
2	USA	13.4	34.7
3	China, Hong Kong SAR	12.0	46.7
4	Germany	4.4	51.0
5	Singapore	4.1	55.2
6	Taiwan	4.0	59.2
7	Rep. of Korea	3.8	63.0
8	Japan	3.7	66.6
9	Netherlands	2.9	69.6
10	Viet Nam	2.6	72.2
11	United Kingdom	2.1	74.2
12	Malaysia	2.0	76.3

13	India	1.8	78.1
14	France	1.6	79.7
15	United Arab Emirates	1.3	81.0
16	Canada	1.3	82.3
17	Czechia	1.3	83.6
18	Thailand	1.2	84.7
19	Italy	1.0	85.8
20	Philippines	1.0	86.7
21	Russian Federation	0.9	87.7
22	Australia	0.9	88.6
23	Poland	0.8	89.3
24	Brazil	0.7	90.1

Source: Authors

Table 4 provides an overview of the country's shares in global digital imports, accounting for 90% of the total. At the forefront, China holds the largest share with 21.3%, followed by the USA at 13.4% and China, Hong Kong SAR at 12.0%. These top three countries alone constitute 46.7% of global digital imports. Germany, Singapore, Taiwan, the Republic of Korea, Japan, the Netherlands, and Vietnam also feature prominently, with their cumulative contributions totalling 72.2%. The table further includes the United Kingdom, Malaysia, India, France, the United Arab Emirates, Canada, Czechia, and Thailand, all contributing to the cumulative percentage, which reaches 84.7% by the 18th country on the list.

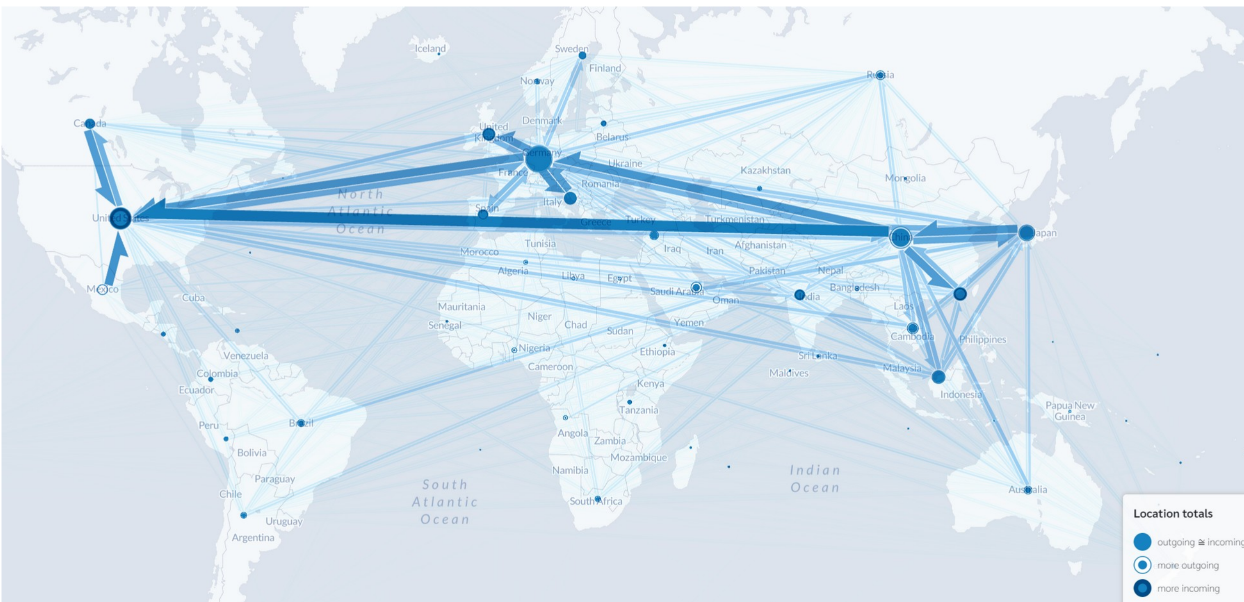
5. Trade in DPTs in total trade: Descriptive analysis

Due to the pervasive nature of digitalisation, trade in DPTs has gained significant ground over the last years. By contrasting the trade in all products with digital products based on our DPTC, we can find evidence of the prominence of trade in DPTs. Figures 3A and 3B below illustrate this comparison, shedding light on various aspects of trade in DPTs.

First, let's analyse the proportion of Digital Product Technologies (DPTs) in total trade for 2012 and 2019. In 2012, DPTs accounted for 11.5% of both imports and exports. By 2019, this figure had increased to 14% for both imports and exports. This growth, representing an approximate 21.3% increase in both imports and exports over seven years, indicates a steady and significant rise in the importance of DPTs in global trade. This trend underscores the expanding role of digital technologies in international commerce and the growing reliance of economies on these technologies for trade activities.

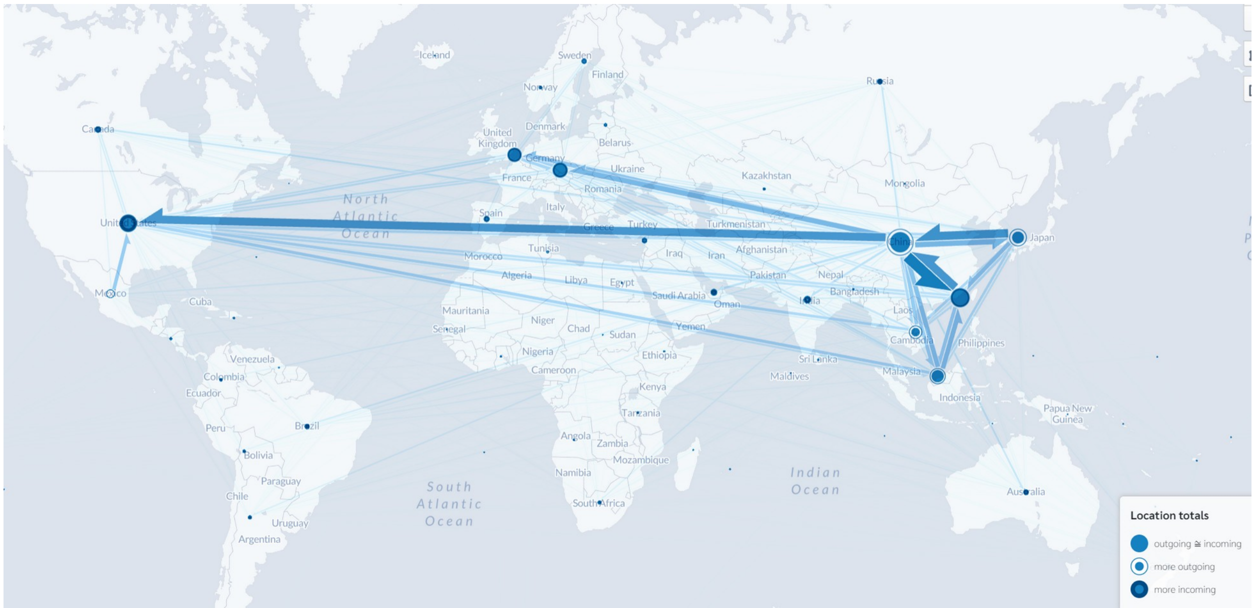
Second, trade in DPTs has evolved differently across countries and regions. The most notable observation from Figures 3A and 3B is the decreasing significance of Europe and North America in the DPTs trade compared to their role in overall trade. This starkly contrasts with the prominence of DPTs trade in East and Southeast Asian countries. In this context, the role of Europe and the US as primary importers of these products becomes evident.

Figure 3A - International trade in all products



Source: Authors

Figure 3B - International trade in DPTs



Source: Authors

The distinction becomes more apparent when comparing the proportion of intra-regional trade for all products versus DPTs, as shown in Tables 5 and 6 below. Regarding all product trade, Europe has the highest intra-regional trade share (65.6%), followed by East and Southeast Asia (54.8%). However, for DPT trade, East and Southeast Asia takes the lead with an impressive 86.0% share of intra-regional trade, while Europe's share drops to 40.8%.

Table 5. Bilateral Exports and Imports by Region in Total Trade

	Importing region				
Exporting region	Asia	Europe	Americas	Africa	Other regions
East and Southeast Asia	54.8%	15.8%	34.3%	24.7%	34.0%
Europe	14.7%	65.6%	21.5%	33.0%	25.4%
Americas	13.5%	8.6%	37.4%	8.3%	11.8%
Africa	2.4%	2.8%	1.2%	16.7%	5.3%
Other regions	14.6%	7.1%	5.6%	17.3%	23.4%

Source: Authors

Table 6. Bilateral Exports and Imports by Region in Trade of DPT

	Importing region				
Exporting region	Asia	Europe	Americas	Africa	Other regions
East and Southeast Asia	86.0%	50.9%	73.2%	61.9%	78.2%
Europe	5.7%	40.8%	8.1%	22.6%	10.7%
Americas	6.9%	7.0%	17.6%	5.7%	7.4%
Africa	0.0%	0.3%	0.0%	3.9%	0.1%
Other regions	1.4%	1.1%	1.0%	5.9%	3.6%

Source: Authors

The data presented in these Tables demonstrate the significant role that East and Southeast Asian countries play in the global market for DPTs. These regions have established themselves as major hubs for DPT manufacturing, a fact that is reflected in their status as the largest exporters of DPTs worldwide. The extent of their integration into the global DPT market is evident from the high percentages of DPTs that other regions import from East and Southeast Asia. For instance, the Americas import a substantial share of their DPTs, 73.2%, from these Asian regions. This figure underscores the pivotal role that East and Southeast Asian countries hold in supplying DPTs to various parts of the world, indicating their influence and importance in the global supply chain of DPTs.

6. Network analysis

Descriptive analysis of trade flows in DPTs and total trade provide some preliminary stylised facts on the structure and dynamics of DPTs. The subsequent step of our research involves integrating our DPTC within a network analysis methodological framework, which we apply to unveil the global DPTs network structure. Our objective with this method is to chart and understand the structure of DPTs production and trade flows. Through network analysis, we investigate the connections between countries in the DPT global market, especially regarding bilateral export and import relationships between countries. This approach helps us gain insight into the worldwide spread and movement of digital technologies. It uncovers the central nodes and connections in the international DPT network and identifies key production centres and export destinations. It also highlights the major contributors and those lagging in global DPT trade.

To capture both the structure and its evolution over the recent past, our analysis focuses on data from two specific years: 2012 and 2019. We chose these two data points based on the presumption that international trade structures are relatively stable and building export capabilities in DPTs take significant time and long investment cycles, rendering the examination of annual data redundant. We selected the year 2019 as it is the last year before the disruptions caused by the COVID-19 pandemic, which significantly impacted international trade. We chose 2012 as it provides a considerable time gap (8 years) from the final year and represents the earliest year with data available under the HS2012 classification, closely aligning with the HS2017 classification. Using data from years before 2012 would necessitate conversion from older HS classifications, potentially compromising the reliability of the analysis.

In our study, we explore two distinct network types to understand the trade of digital products. The main focus is on the unilateral network, which is detailed below. This network uses bilateral trade balances to differentiate between net exporters and net importers of digital products, emphasising the outdegree centrality. This measure clarifies whether a country primarily exports or imports digital products, offering insights into its role in the global digital market.

As a robustness check, we also examine a bilateral trade network, which can be found in the appendix of the paper. This network is vital for identifying key connections in digital product trade. It aggregates (sum) the imports and exports of digital products between two countries. The countries that occupy central positions in this bilateral network are of paramount importance in the global trade of these commodities. However, it's important to note that this network does not explicitly reveal if a country is mainly an exporter or importer of digital products, which is why the unilateral network is more crucial to our analysis.

In our study, determining the threshold for including edges was crucial. We aimed to ensure that our analysis remained consistent with well-established patterns in the trade of DPTs that we discussed in the previous sections. To achieve this, we applied a threshold that would effectively capture the major players in the digital product market.

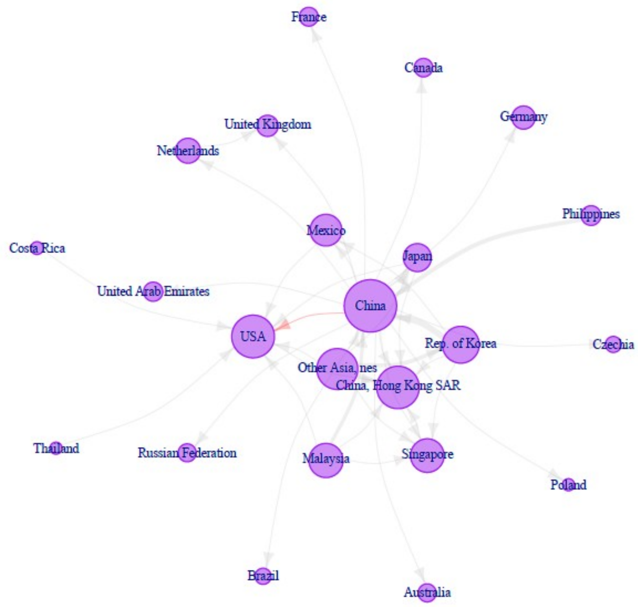
Specifically, we wanted to include countries that collectively represent the majority of the market share in this sector.

After careful consideration and sensitivity analyses, we set the threshold at 5 billion USD. This figure effectively encompasses countries responsible for 90% of the total exports of digital products globally. By selecting this threshold, we aimed to include the most significant contributors to the digital product trade while maintaining a focus on those nations with substantial export volumes. This approach ensures that our analysis provides a comprehensive view of the global digital product market, highlighting the key countries that drive most of the trade in DPTs.

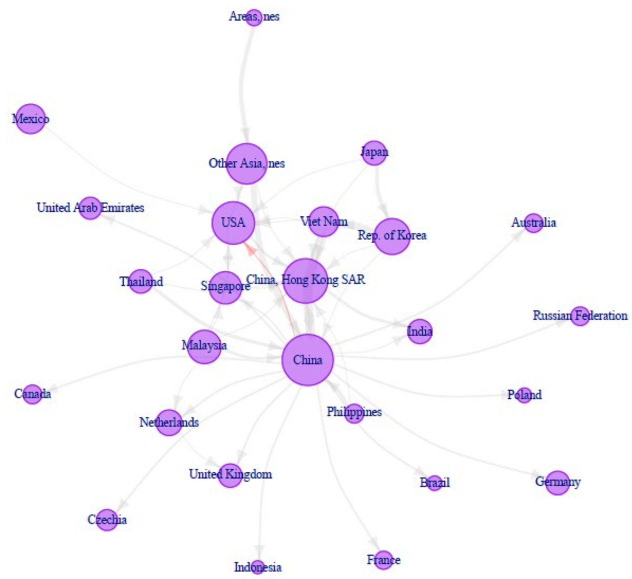
6.1 Results/Findings for Total DPTs – unilateral network

In this section, we delve into the results of the Unilateral Network focusing on Total Digital Products, focusing on a critical aspect of international trade dynamics: the trade balance in DPTs. This component is crucial in understanding the flow of digital products across global markets. By analysing the difference between bilateral exports and imports of digital products, we gain insights into various countries' trade positioning and strategic interactions within the digital technology sphere. This section presents a detailed examination of these dynamics, shedding light on the intricate patterns of trade imbalances and their implications in digital product exchange.

Figure 4: Dynamics of Unidirectional Network Structure for Total Digital Product (Threshold = 5bi)



Year = 2012



Year = 2019

Source: Authors

Table 7. Analysis of Trade Balance Network Dynamics: 2012 vs. 2019

Year	Threshold	Density	transitivity	diameter
2012	5	0.077	0.278	2
2019	5	0.071	0.247	3

Source: Authors

The analysis of the trade balance network results for 2012 and 2019 reveals a trade landscape where existing trade balance connections coexist. The network displays moderate clustering tendencies, indicative of forming trade communities around shared trading partners while maintaining an efficient structure[1] with a consistent diameter. In the trade network data, density values of 0.077 in 2012 and 0.071 in 2019 represent moderate connectivity between countries. This moderate density indicates a significant but not saturated number of trade connections, a scenario that is expected in global trade due to constraints like geographic distance, economic policies, and differing production capabilities. Such a level of density has several implications: it signifies

[1] Overall, the trade balance network demonstrates efficiency through a balance of not being overly dense (which could make the network complex and unwieldy), maintaining moderate clustering (which fosters strong trade communities without becoming insular), and having a small and consistent diameter (ensuring that trade routes are direct and accessible). This configuration suggests a trade network that is adaptable, with the capacity to integrate new connections while maintaining a structure that supports efficient trade relationships.

potential for growth in trade connections, allowing countries to establish new partnerships or strengthen existing ones; it offers room for diversification in trade relationships, enhancing the resilience and stability of the global economy by reducing dependence on a few partners; and it suggests a balance in network connectivity, efficiently avoiding the complexities of an overly interconnected system and the underutilisation of a sparse network. These insights underscore the evolving dynamics of international trade relationships, highlighting both the interconnectedness and opportunities for development within the trade balance network.

Table 8. Unilateral Trade Network Metrics for Digital Product Trade by Country (2012-2019)

Country	Outdegree Centrality 2012	Outdegree Centrality 2019	Eigenvalue Centrality 2012	Eigenvalue Centrality 2019	Betweenness 2012	Betweenness 2019
Argentina	0	0	0.014	0.008	0	0
Australia	0	0	0.056	0.052	0	0
Austria	0	0	0.007	0.006	0	0
Belgium	0	0	0.002	0.002	0	0
Brazil	0	0	0.054	0.038	0	0
Canada	0	0	0.064	0.052	0	0
Chile	0	0	0.013	0.010	0	0
China	37	33	1.000	1.000	193	266
Hong Kong SAR	0	2	0.588	0.733	0	0
Colombia	0	0	0.012	0.012	0	0
Costa Rica	5	0	0.047	0.000	0	0
Czechia	2	2	0.040	0.068	0	11
Denmark	0	0	0.000	0.000	0	0
Finland	0	0	0.009	0.005	0	0
France	0	0	0.063	0.050	0	0
Germany	8	9	0.108	0.111	58	135
Hungary	2	0	0.014	0.008	1	0
India	1	1	0.000	0.100	0	14
Indonesia	0	0	0.022	0.025	0	0
Ireland	1	3	0.001	0.017	0	0
Italy	0	0	0.022	0.020	0	0
Japan	10	8	0.117	0.063	40	0
Kazakhstan	0	0	0.006	0.000	0	0
Malaysia	13	7	0.243	0.205	0	13
Mexico	3	3	0.196	0.108	7	0

Netherlands	7	8	0.102	0.107	182	303
New Zealand	0	0	0.006	0.006	0	0
Norway	0	0	0.010	0.010	0	0
Other Asia, nes (Taiwan)[2]	14	12	0.501	0.542	0	114
Pakistan	0	0	0.006	0.006	0	0
Paraguay	0	0	0.005	0.003	0	0
Peru	0	0	0.007	0.008	0	0
Philippines	7	5	0.087	0.058	0	212
Poland	0	0	0.029	0.031	0	0
Rep. of Korea	10	9	0.365	0.309	141	238
Russia	0	0	0.049	0.050	0	0
Saudi Arabia	0	0	0.023	0.000	0	0
Singapore	1	3	0.163	0.177	0	46
Slovakia	0	0	0.017	0.009	0	0
South Africa	0	0	0.012	0.016	0	0
Spain	0	0	0.017	0.022	0	0
Sweden	1	1	0.001	0.002	12	7
Switzerland	0	0	0.007	0.010	0	0
Thailand	5	6	0.060	0.074	68	3
Turkey	0	0	0.020	0.017	0	0
UAE	1	0	0.066	0.080	4	0
United Kingdom	0	0	0.053	0.069	0	0
USA	10	9	0.617	0.514	36	30
Viet Nam	6	17	0.026	0.132	15	63
Areas, nes	0	2	0.000	0.022	0	0
Kuwait	0	0	0.000	0.006	0	0
Romania	0	0	0.000	0.000	0	0

Source: Authors

Examining trade balance dynamics within the total digital products network between 2012 and 2019 presents an intricate landscape of winners, losers, and transformative shifts. Through the lens of network centrality metrics, the changing role of countries within this digital trade ecosystem becomes apparent. The network's structure, governed by centrality degree, eigenvector centrality, and betweenness centrality, underscores evolving influence, connection, and intermediation patterns.

[2] The United Nations refrains from explicitly providing the trade of Taiwan, but "Other Asia, nes" is a good proxy for it. According to UN Statistics: "[I]n the partner breakdown, Taiwan, Province of China, is included under "Other Asia, not elsewhere specified" (code 490). Data for "Other Asia, nes" is available only to international organizations. In principle, trade data for territories belonging to Asia, but not specified by country, could end up in code 490. In practice, only trade of Taiwan, Province of China is included under this code, except for several countries (such as Saudi Arabia, which report all of their exports to unknown countries)." (UN Statistics, 2021)

In the context of trade balance centrality, several countries have shown marked advancements. China and Hong Kong, for instance, continue to hold significant positions, reaffirming their status as key centres in the digital product trade arena. Countries such as Vietnam, Malaysia, and the Philippines have become more central in the network, winners in this process. However, not all countries have seen positive changes. The United Arab Emirates and Argentina, for example, have shown only marginal progress in enhancing their centrality. Brazil, on the other hand, has either stagnated in its influence within the network. Considering the significant impact of the 2014 closure of a large-scale Intel factory in Costa Rica, which specialised in producing electronic components like semiconductors that fall within our classification, Costa Rica's absence from the trade network between 2012 and 2019 is a notable case. This event underscores the influence of major industrial changes on a country's participation in global trade networks.

The analysis of Digital Product Technologies (DPT) trade within Europe highlights a distinct pattern compared to other products in the EU market. The trade network for DPTs is characterised by a less dense and centralised structure, which is particularly noteworthy given the EU's single market typically fosters increased intra-EU trade. This divergence suggests that DPT trade dynamics are influenced by factors unique to this sector.

The data reveals that Germany holds a relatively higher centrality within the region for DPT trade. In contrast, the other major European economies do not exhibit the same level of centrality. This disparity has led to a fragmented trade structure within the EU for DPTs. The fragmentation is further accentuated as these economies are influenced by external central hubs of DPT trade, diverging from the more integrated trade patterns generally observed in the EU.

The network metrics provide insights into this trend. For instance, while China shows high outdegree centrality and betweenness in both 2012 and 2019, reflecting its dominant role in the global DPT market, European countries like France and the United Kingdom display low centrality and betweenness in the same period. This indicates their peripheral role in DPT trade. Similarly, countries like Vietnam show a significant increase in centrality, suggesting emerging new hubs in the DPT trade network.

China's sustained dominance in centrality metrics cements its standing as a digital trade powerhouse. The emergence of Vietnam as a notable winner indicates its growing prominence as an influential player within the network. Vietnam's ascent as a significant player in the digital trade network can be attributed to a series of strategic moves, including substantial investment in technology infrastructure, implementation of favourable policies to attract foreign investment, a focus on education and skill development in IT, and active participation in strategic partnerships and trade agreements that bolster digital trade. Additionally, Vietnam has concentrated on localising and diversifying its digital product offerings and expanding its e-commerce platforms, effectively enhancing its global digital trade presence. In contrast, the USA has experienced a moderate decrease in its centrality within this domain, possibly due to increased global competition, shifts in trade policies, and changing internal market dynamics, marking a dynamic shift in the landscape of global digital trade. Conversely, the USA experiences a moderate dip in centrality metrics, signifying a slight reduction in its relative influence within this digital trade landscape.

Table 9. Summary of Result Meanings and Descriptions for Unilateral Networks

Value	Meaning	Change over time	Regional aspects
Eigenvalue Centrality	Eigenvalue centrality is a measure of the importance of a node in a network. A node is crucial if it connects to other nodes that are also important in the network.	China is the most central country, with a value of 1.00 in both 2012 and 2019. The subsequent most essential nodes/countries are the US (0.617), Hong Kong (0.588), and Taiwan (0.501). While both HK and Taiwan increased their centrality in 2019, the US decreased it, indicating a movement towards East Asia in terms of digital goods production.	In regional terms, the most critical regions in the network in 2012 were North America and Asia. In country terms, North America is mainly represented by the United States and Canada, while Asia has China, Taiwan, Hong Kong, Japan, and Singapore as its most relevant players. In 2019, the same regions remained important, but there was an increase in the importance of India, representing South Asia. Europe is less important in the network, with Germany and the Netherlands being the only countries with high scores in both years.
Outdegree Centrality	Outdegree centrality	For 2012, we find that China had the highest number of outgoing	Regional analysis indicates that Asia had the highest number of

	measures the number of outgoing links from a node in a network. It is important to note that this data only reflects the number of outgoing links in a particular year and does not reveal the overall trends over time.	links with a value of 37, followed by Malaysia and Taiwan with 13 and 14 outgoing links, respectively. The US and Japan had ten outgoing links each. In 2019, the number of outgoing links decreased for most countries, and China continued to have the highest value with 33 outgoing links. Vietnam, which did not appear in 2012, had the second-highest number of outgoing links in 2019, with a value of 17.	outgoing links in 2012 and 2019, with China and Malaysia being the top two countries in 2012 and China and Vietnam in 2019. In contrast, Europe did not have any outgoing links in the provided data for either year, and the Americas had relatively fewer outgoing links than Asia
Betweenness	In digital product imports and exports, betweenness centrality measures a country's influence over the flow of these products in a network.	In 2012, China showed the highest value of 193, followed by the Netherlands with 182 and South Korea with 141; the top three countries indicated they were relevant hubs for digital product flows. In 2019, the values for betweenness centrality increased for most countries, with the top three Other Asian countries, such as the Philippines, Taiwan, and Singapore, also having high values in 2019. Interestingly, Japan had a decline in its influence over time, from 40 in 2012 to of zero in 2019.	Regarding regional analysis, we can observe that Asian countries dominated the top positions in 2012 and 2019, indicating that Asia is a hub for digital product flows, with China being the most influential country. Europe had relatively low values in both years, suggesting that it plays a less central role in the flow of digital products.

Source: Authors

7. Conclusion

Our new DPTC offers a nuanced way to analyse the structure and evolving dynamics of global DPTs trade networks. By focusing on production technologies with digital potential and excluding consumables, we achieve a finer granularity in mapping the export and import of technologies used in production processes. By considering specific products and trade networks, our detailed classification also holds the potential to chart digital global value chains and, over time, track how countries progress along these chains. The additional division between final goods, parts, and instruments, although not analysed in this initial paper, has the potential to provide further nuance to these networks.

In a preliminary application of our classification, the network analysis detailed in section 6, three main trends emerge. Firstly, China has become the central hub in the global network of digital production technology, while the USA has reduced its importance in the network. Second, in Southeast Asia, new entrants are coalescing around China, creating a regional hub characterised by dense bilateral flows of DPT components. Third, and opposite to what holds for China and South East Asia, Europe exhibits a fragmented network, with limited bilateral DPT trade centred around Germany. Despite Germany's orchestrating role, the European single market has not relied on intra-regional trade for most of its DPT imports. Middle-income countries like Brazil and South Africa remain largely peripheral in these networks. .

This is an initial analysis using our DPTC, whose applications we believe are potentially numerous. We anticipate further refinement and use of this classification for more deep-dive analysis at the regional and product/category-level trade studies. Given the geopolitical significance of the technologies in our new classification, future research could explore this perspective for additional insights. For example, a natural follow up from this paper will be the analysis of trade networks by focusing on the three segments of products that we were able to identify with our classification: final products, parts and instruments. The distribution of value across the network highly depends on countries' specialisation in different segments of digital value chains. The main limitation of our classification is the exclusion of services due to the lack of comparable international data, such as UN Comtrade data. This aspect represents a critical area for future data development and analysis.

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Annex I. Classification of DPT Products: Final Products, Parts, and Instruments

The total 127 DPT products can be further divided into final products, parts, and instruments. The intersection between classes 84, 85 and 90 (HS classification) and BEC classes 41, 42 and 22 allow us to distinguish between final goods (i.e., capital goods BEC class 41) and parts (BEC class 42 and 22). Given our attention to digital production technologies, we wanted to disaggregate our classification further, emphasising the instruments' role. Therefore, the class 90 groups both final goods and parts of instruments.

Table A1. Classification of Digital Production Technologies by Type

Type DPT	*HS 2017 6-Digits*	*BEC 4*	*Description*
Final Good	*8842320, 842330, 842381, 842382, 842389, 842390, 844331, 844332, 845611, 845612, 845690, 845811, 845891, 845921, 845931, 845941, 845951, 845961, 846012, 846022, 846023, 846024, 846031, 846221, 846241, 846520, 847130, 847141, 847149, 847150, 847160, 847170, 847180, 847190, 847780, 847950, 848610, 848620, 848630, 848640, 851521, 851531, 851580, 851712, 851761, 851762, 851769, 852190, 852352, 852692, 852852, 852862, 854290*	*41*	*Various final goods including scales, machinery, and data-processing machines*
Parts	*847330, 847790, 848690, 851770, 852351, 852990, 853331, 853339, 853340, 853390, 854040, 854089, 854121, 854129, 854140, 854150, 854190, 854231, 854232, 854233, 854239*	*42*	*Parts and accessories for various digital production machinery*
Instruments	*901210, 901290, 901380, 901390, 901520, 901540, 901580, 901590, 901600, 901730, 902219, 902229, 902410, 902480, 902490, 902580, 902590, 902610, 902620, 902680, 902690, 902710, 902720, 902730, 902750, 902780, 902790, 902810, 902820, 902830, 902890, 902910, 902920, 902990, 903010, 903031, 903032, 903033, 903039, 903040, 903082, 903084, 903089, 903090, 903141, 903149, 903180, 903190, 903210, 903220, 903281, 903289, 903290*	*41, 42*	*Various instruments, including surveying instruments, measuring devices, and parts thereof*

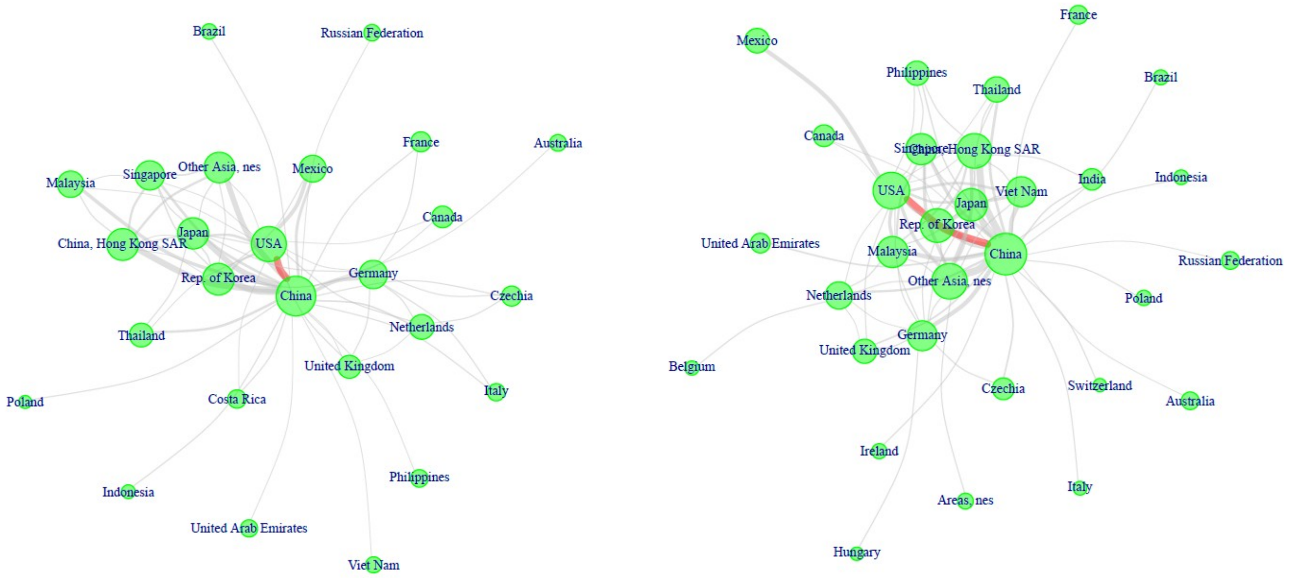
Table A2. Detailed Classification by Digital Process

Products	***Digital process***
903180, 902780, 902790, 903149, 902620, 903190, 902750, 903090, 902710, 902920, 902610, 903141, 902690, 903210, 852190, 902730, 901580, 853340, 902720, 902680, 902830, 901210, 902219, 902890, 903033, 901590, 903089, 902990, 902590, 903039, 902580, 902820, 902480, 903010, 902910, 903084, 842390, 901290, 901730, 842381, 901520, 902810, 903031, 902410, 853390, 902229, 842382, 901600, 903032, 842389, 853339, 901540, 842320, 853331	*Data collection*
851712, 851770, 847790, 847780, 847950, 845611, 845811, 851580, 846221, 851521, 851531, 845891, 845961, 846241, 846023, 846024, 846031, 845931, 846520, 845921, 846012, 845690, 846022, 845941, 845612, 845951	*Integrated data-enabled devices/machines*
854231, 854239, 854232, 847130, 847330, 847150, 847180, 854129, 847149, 847160, 847141, 854121	*Data processing*
854140, 901380, 852852, 848630, 901390, 852862, 854040	*Data display*
851762, 851769, 851761, 903040, 852692	*Data transmission*
903289, 903290, 903281, 903220	*Actuators*
847170, 852351	*Data storage*
852990, 848620, 848690, 844331, 854290, 854233, 844332, 854190, 848640, 847190, 852352, 903082, 848610, 854150, 842330	*Multiple*

Annex II. Results for the Bilateral Network on Total Digital Products

For robustness and added reliability, we provide the outcomes of our network analysis, which concentrates on the bilateral trade relationships that highlight critical links in the trade of digital products. For every trade interaction between two nations, we combine the imports and exports of digital products, which are then adjusted based on final products, parts, and instruments.

Figure A1: Bilateral Trade Network of Total Digital Products (Threshold: 5 Billion)



Year = 2012 *Year = 2019*

Table A3. Evolution of Bilateral Trade Network Properties in the Trade of Total Digital Products (Threshold: 5 Billion)

	Threshold	Density	transitivity	diameter
2012	5	0.189	0.360	2
2019	5	0.163	0.428	3

Analysing the bilateral trade network for digital products between 2012 and 2019 reveals dynamic shifts in network characteristics. While China and the USA maintain dominant roles as key exporters and connectors, Vietnam and Hong Kong show noteworthy improvements in influence and connectivity. The network becomes slightly less dense over time, hinting at reduced overall interconnectedness, but increased transitivity suggests the emergence of more tightly-knit trade clusters. The network's diameter expands slightly, reflecting changing trade partnerships and connections among countries. These changes point to an evolving landscape where new players gain prominence, trade relationships become more clustered, and the overall structure of the network undergoes subtle adjustments.

Table A4. Bilateral Trade Network Metrics for Digital Product Trade by Country (2012-2019)

Country	Centr Degree 2012	Centr Degree 2019	Centr Eigen 2012	Centr Eigen 2019	Betweenness .2012	Betweeness. 2019
Areas, nes	0	1	0	0.013	0	0
Australia	1	1	0.038	0.033	0	0
Belgium	0	1	0	0.002	0	0
Brazil	1	1	0.030	0.020	0	0
Canada	2	2	0.081	0.055	0	0
China	25	26	1.000	1.000	178	246
Hong Kong SAR	7	11	0.465	0.514	5	39
Costa Rica	2	0	0.042	0	0	0
Czechia	3	2	0.037	0.051	9	0
France	2	1	0.056	0.039	0	0
Germany	9	10	0.194	0.174	85	87
Hungary	0	1	0	0.003	0	0
India	0	2	0	0.056	0	22
Indonesia	1	1	0.023	0.019	0	0
Ireland	0	1	0	0.021	0	0
Italy	2	1	0.027	0.016	52	0
Japan	8	10	0.415	0.346	13	30
Malaysia	4	8	0.173	0.242	1	12
Mexico	3	1	0.198	0.067	0	0
Netherlands	5	7	0.088	0.094	3	71
Other Asia, nes (Taiwan)	6	11	0.378	0.572	0	31
Philippines	1	4	0.045	0.074	0	35
Poland	1	1	0.019	0.021	0	0
Rep. of Korea	8	8	0.457	0.452	44	0
Russia	1	1	0.037	0.033	0	0
Singapore	7	8	0.220	0.223	1	6
Switzerland	0	1	0	0.014	0	0
Thailand	3	4	0.117	0.099	2	0
UAE	1	1	0.042	0.048	0	0
United Kingdom	4	4	0.066	0.064	5	58
USA	14	15	0.670	0.568	48	61
Viet Nam	1	6	0.034	0.228	0	8

The network metrics provided in the dataset offer a window into the changing nature of countries' bilateral trade relationships in the domain of digital products. They allow us to observe variations in the centrality and connections of different countries within the network. These metrics illuminate the changing patterns of trade influence, connectivity, and intermediary positions.

Among the winners in this evolving landscape, China and Hong Kong emerged as notable players with increased centrality degrees, eigenvector centralities, and betweenness centralities. That underscores their growing significance in facilitating trade flows between various countries, particularly in Asia-Pacific. Furthermore, Vietnam's notable advancements in these centrality metrics indicate its increasing influence and success as a critical player in the trade network. The group "Other Asia, nes" (Taiwan), also witnessed considerable growth, indicating enhanced trade roles and more robust connectivity.

Steady performers include the USA and Japan, both maintaining central roles within the bilateral trade network despite minor fluctuations in their centrality metrics. These shifts might suggest slight adjustments in their positions and trade relationships within the network.

On the other hand, certain countries experience shifts in their trade influence. Costa Rica, for example, witnesses a decline in centrality degree, possibly indicating a decrease in its overall trade impact within the network.

The analysis reveals dynamic shifts in the digital product trade network from 2012 to 2019. China, Hong Kong, and Vietnam rose as key players, while the USA and Japan maintained their pivotal roles. Costa Rica experiences a marginal reduction in trade influence. These transformations underscore the fluid nature of trade relationships, highlighting the evolving influence patterns in the global digital product trade landscape. As such, this examination contributes to our broader understanding of how countries navigate and adapt to the changing dynamics of international trade in the digital era.