Capturing the Digital Economy: A Proposed Measurement Framework and its Applications[1]

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Abstract

There is a lack of consensus on an established framework to estimate the digital economy despite the growing trend of digitalization of socioeconomic activities. The authors of this study seek to progress the discourse by defining the core digital products and developing an input-output analytical framework to measure the size of the digital economy and assess its relative importance in national and global production processes. In the final version of this report, this framework is applied to input-output tables compiled from select national statistics offices as well as inter-country tables generated in-house, after which measurement results are analyzed in various ways.

Keywords: digital economy, input-output analysis, national accounts, global value chains

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[1] **This paper is a draft for discussion purposes only**.

The data presented in this paper are not official statistics. Production and trade data from various sources were integrated into the input output economic analysis framework and adjusted as required to conform to specific macroeconomic concepts. As such, data and statistics presented here could differ from relevant official statistics.

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The Core of the Digital Economy: A Proposed Framework

The term "digital economy" is believed to had been coined by Don Tapscott in the 1996 publication *The Digital Economy: Promise and Peril in the Age of Networked Intelligence*. Since then, proposed definitions have evolved and grown in number, varied in concreteness, based on time-bound trends (e.g., incorporation of e-commerce along with the rise of the internet-enabled transactions), and diffed in subclassification (Bukht & Heeks, 2017). A variety of measurement methods have also been brought forward, within and outside the context of gross domestic product (GDP).

The Framework introduced in this section measures the share of GDP attributable to the digital economy, that is, contributions to and from an established set of purely digital products in terms of value-added. Using a core equation centered on the conventional input-output model, the digital economy can be broken down into the following elements: digitally-enabling industry contributions, contributions to digitally-enabled industries, and digital sectors' purchases of non-digital capital. When separated, these measures are meaningful on their own as each can be interpreted uniquely, allowing a flexible calculation and analysis for any user. Data requirements and adjustments to apply the Framework are relatively simple, using readily available National Accounts data such as supply and use tables.

In contrast to this framework, the Organisation for Economic Co-operation and Development (OECD) (Mitchell, 2018) and the U.S. Bureau of Economic Analysis (BEA) (Barefoot, 2018) each proposes a supply and use framework, with their corresponding digital product and industry definitions, to estimate the digital gross value-added (GVA) and complementary indicators such as e-commerce. Notably, the former includes the entire value of transactions involving digital platforms as well as the value of the platforms themselves, while the latter counts only the margins and broker fees on such transactions. Brynjolfsson et al. (2019), meanwhile, supplement the National Accounts calculations by proposing a welfare-based measurement, called GDP-B. Huawei and Oxford Economics (2017) utilize digital spillover effects to estimate the global digital economy, which they estimate to total $11.5 trillion.

Appendix Table 1 in the Appendix compares the proposed framework in this paper with other published estimation methods in more detail. While some economies follow frameworks proposed by such institutions[10], others like People's Republic of China (PRC)[11] have devised their own.

The Digital Economy

There exists a plethora of working definitions for the digital economy encompassing varying inclusions of economic activities. This forms part of the reason why organizations arrive at different results when analyzing the digital economy's development and influence on the wider economy. However, several

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[10] Canada's digital economic estimates are based on the OECD framework (Statistics Canada, 2021).

[11] China Academy of Information and Communication Technology (CAICT) includes value-added of the information industry and contribution to digitized traditional industries using a growth accounting model (CAICT, 2020).

terms related to the concept have been generally agreed upon by experts in the field and may be used as a premise to define the digital economy[12].

To understand how to classify products and industries as digital, one can begin by distinguishing the two main types of data encoding: analog and digital. The term analog refers to information expressed using a "continuously variable physical quantity." A simple example of this *continuously variable physical quantity* is the human voice, which reaches a listener's ear via differences in air pressure. Another example is the high-frequency electromagnetic wave transmitted into the ether, which is the propagation medium for amplitude modulation used on certain radio devices.

In contrast, the term digital refers to the use of discrete encoding (e.g., 0 and 1) instead of a *continuously variable physical quantity* to generate, process, and, store information. In modern cellular phone and radio networks, voice and audio signals are encoded in a stream of discrete values and converted into an analog form only when interacting with the physical medium or a human recipient. As there is a clear delineation between analog and digital technologies, the "digital" economy would naturally encompass those products that are related to digital encoding ("digital products").

The term digital economy is often associated with terms like internet economy, cloud economy, sharing economy, and on-demand economy. While each pertains to a set of business activities, what is common among them is the use of digital technologies, such as software applications, internet infrastructure, and advanced computers, to greatly enhance existing business processes or create new and innovative ones.

Digital products involved in a typical digital transformation[13] are at the core of any definition of a digital economy. Hence, in this paper, the digital economy is ultimately defined as the contribution of any economic transaction involving both digital products and digital industries to the GDP. The centerpiece to this definition is the identification of specific digital products and industries.

Table 1: Main Digital Product Groups [a]

Central Product Classification (CPC) Version 2

Main Activity Group	Code	Product
Hardware	452	Computing machinery and parts and accessories thereof
	475	Disks, tapes, solid-state non-volatile storage devices and other media, not recorded
Software publishing	38582	Software cartridges for video game consoles
	478	Packaged software
	83143	Software originals
	8434	Software downloads

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[12] The technical terms discussed in this section have been verified by ADB consultants whose expertise is in the field of information technology. References to be provided.

[13] The changes brought about by the use of digital technologies can generally be categorized in three ways representing different degrees of integration: digitization, digitalization, and digital transformation. First, digitization refers to the process of converting data into a digital format, and second, digitalization refers to the incorporation of digitized data into established production processes to achieve higher efficiency (Burkett, 2017). The third is digital transformation which is similar to digitalization except that it refers to a more extensive integration of digital products, such as a large enterprise involving hundreds of employees and tools in its strategic use of digital technologies.

Table 1: Main Digital Product Groups [a]

Central Product Classification (CPC) Version 2

Main Activity Group	Code	Product
	84391	On-line games
	84392	On-line software
Web publishing	83633	Sale of Internet advertising space (except on commission)
	843	On-line content [b]
Telecommunications services	841	Telephony and other telecommunications services
	842	Internet telecommunications services
Specialized and support services	8313	Information technology (IT) consulting and support services
	83141	IT design and development services for applications
	83142	IT design and development services for networks and systems
	8315	Hosting and IT infrastructure provisioning services
	8316	IT infrastructure and network management services

[a] Corresponding industry groups and codes in International Standard Industrial Classification of All Economic Activities (ISIC) Revision 4 are included in the Appendix Table 2.

[b] Excluding items under CPC Ver. 2 843 already counted under Software Publishing – 8434, 84391, 84392

Source: Authors' methodology using United Nations' *Central Product Classification: Version 2* (2008).

The measurement framework discussed in this paper ("the Framework") defines digital products to be goods and services with the main function of generating, processing and/or storing digitized data[14]. The primary producers of such products (i.e., industries that supply these products more so than any other industry in the economy) are considered as the digital industries. The Framework identifies core digital products[15] that can be summarized into five main product groupings: (1) hardware, (2) software publishing, (3) web publishing, (4) telecommunications services, and (5) specialized and support services. The corresponding activity codes from the United Nations Statistical Commission's Central Product Classification (CPC) Version 2 are identified in Table 1. The reason this Framework excludes certain products that other frameworks may include as digital or digitalized is discussed in **Box 1**.

Box 1: Digitally-enabling and digitally-enabled products

Components and accessories supporting digital goods and services, although necessary in the production of digital products, are not considered as part of the core digital products. Without the assembly process, such products cannot generate, process, and store data by itself. For example, semiconductors used for electrical conductivity are integral components of computer manufacturing but, by itself, do not have a direct function in relation to digitized data. In this paper, these products are referred to as "digitally-enabling products." While not considered as a core digital product, *digitally-enabling products* are still captured in the Framework's core digital economy equation, as will be discussed under the theoretical framework.

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[14] ICT in national accounts usually refers to anything related to the equipment and techniques in handling and processing information, which do not necessarily encompass exclusively digital products.

[15] In consequence, digital industries are the main producers of the core digital products identified by the Framework..

For the same reason, products that use digital products as components or accessories are not considered core digital products as well. While digital technologies may play a significant role in the production process of a certain product, its primary function does not change relative to its original function using only analog products. For example, car manufacturing companies are increasingly adding digital components into their vehicles, which includes connected in-car entertainment experiences, vehicle systems management, and self-driving capabilities among others. Despite these novel features, highly digitalized cars are still considered as transportation equipment, not digital hardware. In this paper, these products are referred to as "digitally-enabled products." Like *digitally-enabling products, digitally-enabled products* are also captured in the Framework's core digital economy equation.

Source: Authors' methodology.

As a consequence of narrowing down a core set of digital products, the Framework prevents inaccuracies resulting from attempts to measure the portions of mixed product groupings relating to digital products (e.g., digital microphones among total microphones) and from having to make judgment calls on how "digital" certain products are (e.g., the percentage of "smart" appliances that is digital). Nonetheless, disaggregation and adjustments among products may still be necessary depending on the data granularity of the economy in question, however, measurement error is minimized compared to more general and relatively arbitrary classification schemes. The following provides a detailed discussion of the product groupings identified in **Table** 1.

Hardware

Digital hardware refers to the physical component of digital computing technologies. Basing the digital economy on the products of the entire information and communications technology (ICT) sector would likely overestimate what is actually "digital," as ICT products include both analog and digital technologies. Instead, only hardware that relates to primary digital technology is considered. This includes two main components: computers, computer parts and peripheral equipment (CPC ver 2. Code 452), and unrecorded digital media (CPC ver 2. Code 475).

Computers, computer parts and peripheral equipment

Computers and computer parts include the entire assembled physical infrastructure of a data processing machine itself (e.g., laptops, personal digital assistants, mainframe computers) and all parts necessary for it to operate (e.g., central processing unit, volatile memory). The hardware itself only allows basic functions to run (e.g., to turn on), and system software is always required to allow a computer to process digitized information (Mullins, 2011). Therefore, computers are generally classified as hardware, with its pre-installed system software assumed to be embedded.

Unrecorded digital media

Unrecorded digital media pertains to blank physical devices that store data coming from computers[16] and other devices with computing abilities. The most common examples of unrecorded digital media include magnetic storage (e.g., hard discs, floppy discs), optical storage (e.g., compact discs [CDs], digital versatile discs [DVDs]), and flash memory (e.g., memory sticks, solid-state drives). Similar to computers, these also come with system software required to store data (Mullins, 2011).

Another type of hardware that should theoretically be classified as a digital product are analog-to-digital converters (ADCs). These are electronic integrated circuits that convert analog signals to digital output.

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[16] Note that memory that is built in or essential for the use of computers would fall under computers and computer parts.

These function independently from a computer and are used by many types of digital sensors, and may be produced in-house for different types of equipment such as in cellular phones. However, ADCs are not easily identifiable in most detailed levels of product classification systems, such as in CPC Ver. 2 [17], and thus may not be captured[18] within the digital economy estimates of the Framework.

Software publishing

While hardware refers to the physical parts of a computer, software generally refers to a programming code, which is a set of instructions by which a computer operates. Software publishing pertains to software that is made publicly available as ready-to-use software for consumers[19]. There are three main modes for the distribution of software: via physical media (e.g., boxed software sold on shelves), via online distribution direct to consumer (e.g., online stores that sell licenses to download the software), and via application marketplaces (e.g., first-party mechanisms like App Store and Google Play). Two main types of software publishing are considered: system software (portions of CPC ver 2. Code 478 and 83143) and application software (CPC ver 2. Code 38582, 478, 83143, 8434, 84391, and 84392).

System software

System software is essential in the most fundamental functions of a computer system. For this reason, they are also referred to as "low-level software." The operating system (OS) that comes with a computer or any device that runs on digital computing technology is the most well-known type of system software and allows users to interact with the hardware. Popular examples of an OS include Microsoft Windows, Mac OS or Apple iOS, Android, and Linux . Other kinds of system software include device drivers which allow input and output devices to function with an OS (e.g., drivers required to use keyboards, printers), firmware which is embedded in non-volatile digital media (e.g., in ROM and flash chips), programming translators which convert source code (e.g., C++, Java, Python) to machine code, and utility software which aids in the overall function of a computer system (e.g., antiviruses, compression tools, disk cleanup) (Amuno, 2017).

Application software

Application software, or apps, help end-users perform specific tasks, such as presentation and analysis of data, online communication, and graphics design. In contrast to system software, apps are not considered essential for the fundamental functions of a computer system, and their installation is left as an option for the user. Specific types of apps include word processors (e.g., Microsoft Word), spreadsheet software (e.g., Microsoft Excel), database software (e.g., Oracle, MySQL), multimedia software (e.g., QuickTime, VLC), communication software (e.g., Zoom, Skype), and web browsers (e.g., Google Chrome, Internet Explorer), to name a few (Franklin, 2019).

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[17] Following the Standard Industrial Classification (SIC) system, ADCs may fall under electronic integrated circuits (CPC ver. 2 code 47160). In the SIC system, ADCs are specified under SIC code 38250201 (instruments to measure electricity).

[18] In addition, ADCs may not constitute significant components of digital hardware products. In the United States (US), latest data from the Orbis database show that there are only 35 companies that specialize in the manufacture of ADCs out of 1,852 total businesses engaged in instruments to measure electricity.

[19] Custom design and development of software for consumer-specific needs are not under software publishing, and are instead considered as IT design and development services.

Web publishing

Web publishing refers to information generated and published in exclusively digital forms. Firms and institutions publish various kinds of data online. These are contained in files[20]. Some examples of web publishing activities include the video files that Netflix provides as a streaming service, copyrighted stock photos sold by Shutterstock as licenses to use, and online articles published by The New York Times to name a few. The products considered to be published digitized data are included in online content (CPC ver 2. Code 843).

Online content, however, excludes software publishing and advertising space on the internet (CPC ver 2. Code 83633). The former was already discussed as part of the core digital products in the preceding paragraphs. The latter, advertising space on the internet, is essentially published web content, but it is reflected under another classification because of the substance[21] of the product. Therefore, the authors augment this specific product as part of web publishing. A prime example of an institution offering this product is Facebook Inc., which sells advertising space on its multiple social media platforms (e.g., Facebook, Messenger, Instagram) from where the vast majority of its revenues are generated—98.5% in 2019, according to Full Year 2019 Results press release by Facebook.

Telecommunications services

Telecommunications (telecom) refers to the exchange of information (e.g., voice, text, sound, video) through a transmitting medium between two or more stations. When multiple transmitting and receiving stations exchange data among themselves, this is termed a network (Chai & Lazar, n.d.). Product and industry classification systems classify telecom either by types of medium[22] or by types of networks. The CPC classifies telecom by the latter.

In CPC Ver.2, telecom is divided between two major networks: telephony and other telecommunications services (CPC ver 2. Code 841), and internet services (CPC ver 2. Code 842). Both networks utilize a variety of wired and wireless equipment.

Telephony and other telecommunication services

Telephony relates to the primary services provided by telephone carriers and service providers (e.g., calls and short messaging service through mobile phone systems). At its foundation are public switched telephone networks (PSTNs), which refer to the collection of interconnected voice-oriented public telephone networks around the globe, providing landline phone services. Telephony's original forms were purely analog, but over time worked with digital signals and internet connectivity. While PSTNs continue to evolve, entirely new telephony technologies have also been developed and designed specifically for

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[20] A file refers to a named and ordered sequence of bytes. Bytes are comprised of a group of eight bits, the smallest unit of digital information (PREMIS, 2015). Some of the most common file types include PDF for immutable documents, JPEG for images, and HTML for web page creation (Shannon, 2012).

[21] Advertising space on the internet specifies online "space" as the main commodity. This means that a portion of a company's web page or an HTML document is purchased or rented by another company to publish their own content.

[22] There are two main modes of transmission, wired and wireless. Wired refers to the transmission of data using a physical medium (e.g., fiber optic cable, electrical or copper cable) while wireless refers to the transmission of data over electromagnetic waves, without the use of a physical medium (e.g., cellular phone services, wi-fi, bluetooth, satellite transmission) (Chai & Lazar, n.d.). The North American Industry Classification System (NAICS) 2012 and ISIC Rev. 4 apply this categorization, with wireless further divided into wireless excluding satellite and satellite.

digital data transmission, such as the integrated services digital network (ISDN) which is considered as a more efficient alternative to PSTNs (Mitchell, 2019).

Internet services

The internet pertains to the largest global network of computers consisting of private, public, academic, business, and government network. These networks are linked together by data routes employing a broad array of electronic, wireless, and optical networking technologies. The principal and largest data routes comprise the internet backbone, providing networks to smaller distributors or directly to internet service providers (ISPs) (Christensson, 2015).

Types of internet in terms of medium or system used have evolved over the years, resulting in great improvements to data transfer speeds and overall user convenience. These include dial-up through a PSTN, digital subscriber lines (DSL), cable television lines, and fiber optic cables[23]. Nowadays, the boundary between telephony and internet networks is becoming increasingly vague with newer technologies integrating both into one system. One example is the development of voice over internet protocol (VoIP), also known as IP telephony or internet telephony, which allows the transmission of voice communication through the internet (Mitchell, 2019).

In neither "by medium" nor "by network" system of classifying telecom, do granular products categories encapsulate purely digital telecom. Similar to computers, telecom depends on analog components in order to function interactively with humans. While cables and relayed data signals may be analog, they could very well have been converted both from transmitting and for receiving digital terminals. Even the most traditional phone systems existing today, such as private branch exchange (PBX) systems employed by hotels using standard copper wiring and analog telephone sets, are often integrated or supplemented with digital technologies to improve telecommunications functionality. Examples include the incorporation of digital PSTNs and VoIP to enable landline calls from PBX systems to public networks. Given that digitalization is so pervasive in telecommunications infrastructure, the analog components are so well integrated in the dynamics of telecom systems that both have become necessary for service delivery and too interrelated to be viably differentiated. Thus, the Framework does not differentiate these under telecom services.

Specialized and support services

Specialized and support services is a broad term referring to customized and technical services related to core digital products discussed in previous sections (i.e., digital hardware, software, digitized data, and telecom). These services usually provide solutions to entities that don't have the internal human or physical capital for their specific IT needs. The correspondence of CPC with NAICS 2012 succinctly describes these products as: custom computer programming services (CPC ver. 2 Code 8313), computer systems design services (CPC ver. 2 Code 83141 and 83142), data processing, hosting and related activities (CPC ver. 2 Code 8315), and computer facilities management services (CPC ver. 2 Code 8316). While these activities appear similar to each other and are often interrelated, key characteristics differentiate them.

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[23] Data transmission across large networks (such as the internet) involves transmission of data across many nodes, ideally in the most efficient path. As such, transmission between different nodes may have several segments that are wireless, while the rest are wired transmissions.

Custom computer programming

Custom computer programming refers to software and web page design, development, modification, analysis, testing, and support services that are tailored-fit to the needs of a customer (NAICS, 2018). For example, an electricity company might outsource a software developer to create a mobile application that would allow customers to track their electricity usage, provide online billing and payment options, and obtain real-time user reports about power outages among others.

Computer systems design

Computer systems design pertains to the integration of digital products, such as hardware, software, and communication technologies, in order to achieve client-specific solutions. This may entail choosing the optimal and most compatible products, as well as system analysis, design, development, implementation, and maintenance, among others (NAICS, 2018). A simple example is the configuration of an office's LAN among a modem, a router, and all servers and devices (e.g., office-owned computers, personal laptops, wireless printers), including the installation of system software such as a firewall to monitor network traffic.

Data processing, hosting and related services

Data processing, hosting and related services pertains to information services that support the publishing of digital products. Data processing refers to the modification and organization of data using software to produce purposeful information, in a readable and readily usable form for the client (e.g., charts, reports). For example, the Global Data-processing and Forecasting System is one of the major components of the World Weather Watch System, in order to produce meteorological analyses, numerical weather predictions and weather forecasts and warnings (World Meteorological Organization, 2020). Hosting is a general term which means the provision of infrastructure for websites and software to function. Hosting is availed depending on the requirements, and can range from simple leasing of server capacity of a predefined quantity to highly configurable infrastructure as a service (IaaS) platforms[24]. Amazon, Microsoft, and Google are some of the most popular providers of this type of service.

Computer facilities management

Computer facilities management is the on-site management, operation, and support services to clients' computer systems and/ or data processing facilities (NAICS, 2018). As opposed to the previous activities which provide new digital capabilities and components to companies, establishments engaging in computer facilities management deliver maintenance and improvement to already existing computer facilities. For example. one of the leading technology companies in the world, International Business Machines Corporation (IBM) has, as one of its products, an Integrated Workplace Management System which incorporates Internet of Things (IoT) data, analytics, and AI technologies to optimize productivity for facility managers (IBM, 2021).

Evolution of Digital Products and Industries through Time

An important consideration in choosing the elements of the core digital products set is timing. Before the onset of the digital era, only analog existed in the form of analog computers and analog telecom

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[24] Iaas platforms are for time-critical and demanding applications and high traffic websites that can be billed according to resources used per hour or minute.

among others. Gradually, enterprises manufacturing analog commodities started to integrate digital computing technologies into its products. In some cases, analog products were rendered obsolete and were completely replaced with digital forms. As a result, new products and enterprises came into existence. An example is the phasing out of cassette tapes, an analog magnetic medium, with CDs becoming the most widespread form of audio recording. After a few years, CDs became less common (however, not yet obsolete) with the rise of more advanced digital products such as digital media and digital streaming platforms.

Given that a core digital product was defined as one that generates, processes, and/or stores digitized data or is itself digitized data, product groups may only be considered as "purely" digital by the time their analog counterparts had become entirely obsolete, or minuscule to the point of being negligible. The length of transition of a product group before becoming purely digital would vary depending on the conception and life cycle of the product. It may also differ per location, given that markets adopt advancements at different speeds depending on factors such as the degree of trade liberalization, capacities to participate in required stages of production, and consumer demand. This assessment is unnecessary for products that are explicitly distinguished as digital (e.g., online audio content) and products that exist only because of their digital nature (e.g., software).

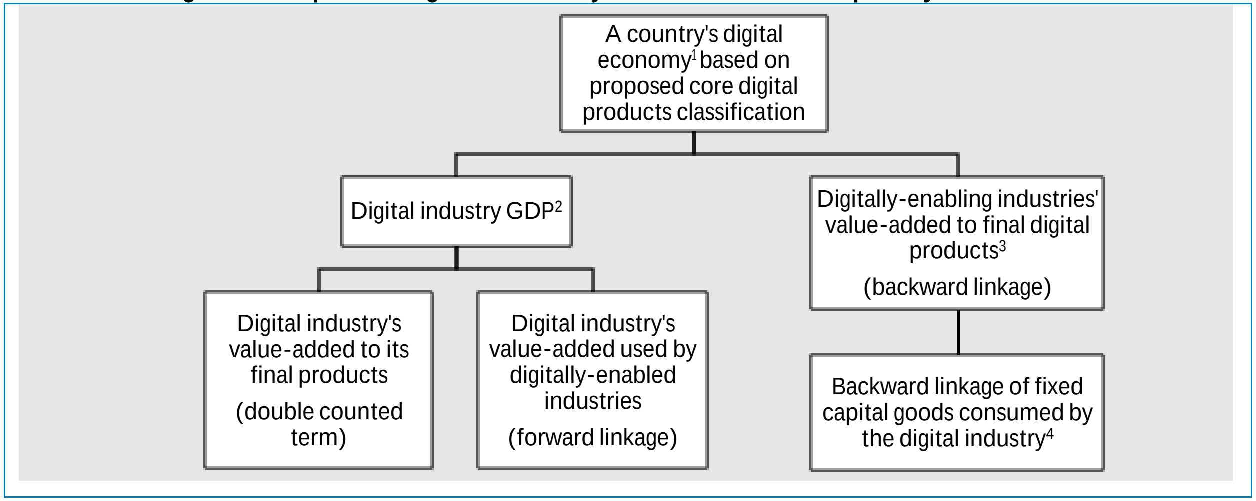
From the identified main digital activities using CPC products, only hardware and telecom services require an assessment of timing. Within these product groups, products such as computers (and parts), unrecorded media, and telecommunications services included analog versions of the same terminology. While it would be difficult to pinpoint the exact moment in time when practically all units in a product group supplied in a given economy became digital, a conservative approximation based on published studies may be the most convenient option. Using the earlier example on cassette tapes, research suggests that US music companies ceased production of these by 2002 (Fung, 2017). Therefore, when measuring the digital economy of the USA, one can extrapolate by saying that the first year for which the definition of core digital products (including blank magnetic media) is applicable to data from 2003 onwards. While this timeline may mirror that of similar economies like Canada, the same cannot be safely assumed for less similar economies.

In such instances where the digital economy must be measured for a period of time in which the identified core digital activities may still include analog units, it is necessary to disaggregate the group to attain the most reasonable allocation of digital and non-digital components (see: *Methodological Requirements* section).

Theoretical Framework

The models involved in the Framework are rooted in input-output analysis, mainly using Leontief coefficients (Leontief, 1936), and forward and backward linkages to directly measure the sectoral interdependencies in terms of value-added contributions.

Figure 1: Proposed Digital Economy Framework Developed by the Authors



1 Given by the $\mathrm{GDP}_{\mathrm{digital}}$ equation, $\mathbf{i}^{\mathrm{T}}\widehat{\mathbf{V}}\mathbf{B}\widehat{\mathbf{Y}}\boldsymbol{\varepsilon}_1 + \mathbf{i}^{\mathrm{T}}\left(\widehat{\mathbf{V}}\mathbf{B}\widehat{\mathbf{Y}}\right)^{\mathrm{T}}\boldsymbol{\varepsilon}_1 - \left[\mathrm{diag}\left(\widehat{\mathbf{V}}\mathbf{B}\widehat{\mathbf{Y}}\right)\right]^{\mathrm{T}}\boldsymbol{\varepsilon}_1 + (\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\widehat{\mathbf{V}}\mathbf{B}\widehat{\mathbf{Y}}\hat{\mathbf{r}}\boldsymbol{\varepsilon}_2$.
2 Given by the second term of the $\mathrm{GDP}_{\mathrm{digital}}$ equation.
3 Given by the first term of the $\mathrm{GDP}_{\mathrm{digital}}$ equation.
4 Given by the fourth term of the $\mathrm{GDP}_{\mathrm{digital}}$ equation.
Source: Authors' methodology.

In this section, the step-by-step derivation of the digital GDP equation is shown. The core of the digital economy is finally captured by a single formula, Equation 10. Figure 1 summarizes the components of this digital economy measurement framework, which is explained in detail in the succeeding sub-sections. Given that each term pertains to a specific measure, the users applying this framework may choose to calculate only certain terms for their purposes (e.g., only term 2 is needed to obtain the forward linkages of digital industries). Moreover, adjustments or extensions to this framework may be adapted to suit specific analyses, such as the measurement of specific global value chain (GVC) indicators, which is covered in a later section.

Deriving GDP in terms of Leontief Inverse Coefficients

In Appendix 1, is it shown that gross outputs $\mathbf{x}$ in a standard input-output table (IOT) can be concisely represented as a function of the Leontief Inverse, $(\mathbf{I} - \mathbf{A})^{-1}$, and final demand, $\mathbf{y}$. Equation 4 describes this relationship.

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{4}$$

Further mathematical manipulations would also allow derivation of a similar equation for economy-wide GDP. For brevity, let the Leontief inverse, $(\mathbf{I} - \mathbf{A})^{-1} \equiv \mathbf{B}$. A direct value-added coefficient vector is defined as

$$\mathbf{v} = (\mathrm{v}_1 \quad \mathrm{v}_2 \quad \cdots \quad \mathrm{v}_n) = \begin{pmatrix} \frac{\mathrm{gva}_1}{\mathrm{x}_1} & \frac{\mathrm{gva}_2}{\mathrm{x}_2} & \cdots & \frac{\mathrm{gva}_n}{\mathrm{x}_n} \end{pmatrix} \tag{5}$$

where $\mathrm{gva}_j, j = 1,2, \dots, n$, refers to the GVA generated by industry j and x_j refers to the gross output of the same industry j. Thus, each entry in $\mathbf{v}$ is the ratio of industry j's GVA to its own output. It is shown below that pre-multiplying $\mathbf{v}$ from Equation 5 to $\mathbf{x}$ from Equation 4 would yield an expression that calculates economy-wide GDP via the production approach[25] (Equation 6). Knowing how to derive economy-wide GDP using the $\mathbf{vBy}$ formulation in Equation 6 is the first step in understanding how a more disaggregated digital GDP is quantified.

$$\begin{aligned} &\mathbf{vx} = \mathbf{vBy}\text{ [26]} \\ &\rightarrow \mathrm{gva}_1 + \mathrm{gva}_2 + \cdots + \mathrm{gva}_n = \sum_{i=1}^{n}\sum_{j=1}^{n} \mathrm{v}_i \mathrm{b}_{ij} \mathrm{y}_j \\ &= \text{economy-wide GDP} \end{aligned} \tag{6}$$

<u>Disaggregating GDP across users and suppliers of value-added</u>

The economy-wide GDP that is computed using Equation 6 can be further disaggregated to an $n \times n$ matrix where an industry's backward and forward linkages can be derived. In particular, this matrix will show an industry's sources (backward linkages) and destination (forward linkages) of value-added. In the context of the digital economy, these respectively refer to industries on which digital sectors are dependent (digitally-enabling industries), and industries which it enables (digitally-enabled industries).

Simple matrix operations involving the $\mathbf{v}$, $\mathbf{B}$, and $\mathbf{y}$ matrices are performed to get an industry's backward and forward linkages. Diagonalizing the direct value-added coefficient vector from Equation (5) and the final demand vector results in matrices $\hat{\mathbf{v}}$ and $\hat{\mathbf{y}}$ below.

$$\hat{\mathbf{v}} = \begin{bmatrix} \mathrm{v}_1 & 0 & \dots & 0 \\ 0 & \mathrm{v}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \mathrm{v}_n \end{bmatrix}; \quad \hat{\mathbf{y}} = \begin{bmatrix} \mathrm{y}_1 & 0 & \dots & 0 \\ 0 & \mathrm{y}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \mathrm{y}_n \end{bmatrix}$$

Pre-multiplying $\hat{\mathbf{v}}$ to $\mathbf{B}$ and then post-multiplying the matrix product to $\hat{\mathbf{y}}$ gives the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix in Equation 7, which is an $n \times n$ matrix that disaggregates the scalar economy-wide GDP across all industries that use and supply value-added.

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}} = \begin{bmatrix} \mathrm{v}_1 & 0 & \dots & 0 \\ 0 & \mathrm{v}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \mathrm{v}_\mathrm{n} \end{bmatrix} \begin{bmatrix} \mathrm{b}_{11} & \mathrm{b}_{12} & \dots & \mathrm{b}_{1\mathrm{n}} \\ \mathrm{b}_{21} & \mathrm{b}_{22} & \dots & \mathrm{b}_{2\mathrm{n}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{b}_{\mathrm{n}1} & \mathrm{b}_{\mathrm{n}2} & \dots & \mathrm{b}_{\mathrm{nn}} \end{bmatrix} \begin{bmatrix} \mathrm{y}_1 & 0 & \dots & 0 \\ 0 & \mathrm{y}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \mathrm{y}_\mathrm{n} \end{bmatrix}$$

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[25] GDP via the production approach is computed by summing across value-added generated by all economic sectors.

[26] In expanded matrix form, $\mathbf{vx} = \mathbf{vBy}$

$$\rightarrow (\mathrm{v}_1 \quad \mathrm{v}_2 \quad \cdots \quad \mathrm{v}_\mathrm{n}) \begin{pmatrix} \mathrm{x}_1 \\ \mathrm{x}_2 \\ \vdots \\ \mathrm{x}_\mathrm{n} \end{pmatrix} = (\mathrm{v}_1 \quad \mathrm{v}_2 \quad \cdots \quad \mathrm{v}_\mathrm{n}) \begin{bmatrix} \mathrm{b}_{11} & \mathrm{b}_{12} & \dots & \mathrm{b}_{1\mathrm{n}} \\ \mathrm{b}_{21} & \mathrm{b}_{22} & \dots & \mathrm{b}_{2\mathrm{n}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{b}_{\mathrm{n}1} & \mathrm{b}_{\mathrm{n}2} & \dots & \mathrm{b}_{\mathrm{nn}} \end{bmatrix} \begin{pmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \\ \vdots \\ \mathrm{y}_\mathrm{n} \end{pmatrix}$$

$$\rightarrow \left(\frac{\mathrm{gva}_1}{\mathrm{x}_1} \quad \frac{\mathrm{gva}_2}{\mathrm{x}_2} \quad \cdots \quad \frac{\mathrm{gva}_\mathrm{n}}{\mathrm{x}_\mathrm{n}}\right) \begin{pmatrix} \mathrm{x}_1 \\ \mathrm{x}_2 \\ \vdots \\ \mathrm{x}_\mathrm{n} \end{pmatrix} = (\mathrm{v}_1 \quad \mathrm{v}_2 \quad \cdots \quad \mathrm{v}_\mathrm{n}) \begin{bmatrix} \mathrm{b}_{11} & \mathrm{b}_{12} & \dots & \mathrm{b}_{1\mathrm{n}} \\ \mathrm{b}_{21} & \mathrm{b}_{22} & \dots & \mathrm{b}_{2\mathrm{n}} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{b}_{\mathrm{n}1} & \mathrm{b}_{\mathrm{n}2} & \dots & \mathrm{b}_{\mathrm{nn}} \end{bmatrix} \begin{pmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \\ \vdots \\ \mathrm{y}_\mathrm{n} \end{pmatrix}$$

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}} = \begin{bmatrix} v_1b_{11}y_1 & v_1b_{12}y_2 & \cdots & v_1b_{1n}y_n \\ v_2b_{21}y_1 & v_2b_{22}y_2 & \cdots & v_2b_{2n}y_n \\ \vdots & \vdots & \ddots & \vdots \\ v_nb_{n1}y_1 & v_nb_{n2}y_2 & \cdots & v_nb_{nn}y_n \end{bmatrix} \tag{7}$$

On the one hand, the rows of the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix correspond to the distribution of the use of the value-added created from a particular industry across all industries in the economy. Adding all row entries, therefore, gives an industry's GDP. Analogously, tracing the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix row-wise corresponds to the forward linkages of the industry. The columns, on the other hand, correspond to the breakdown of value-added contributions of all industries in an economy to final goods production of a particular industry. Thus, summing all entries in a column result in the value of an industry's final products. In parallel, tracing the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix column-wise shows the backward linkages of the industry.

Quantifying the digital economy in a two-industry economy

For simplicity, it can first be assumed that there are two industries in a given economy with industry 1 being the digital industry. This will result in the 2 x 2 $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix below.

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}} = \begin{bmatrix} v_1b_{11}y_1 & v_1b_{12}y_2 \\ v_2b_{21}y_1 & v_2b_{22}y_2 \end{bmatrix}$$

As mentioned in the previous subsection, the sums of the first and second rows are equal to the GDPs of the digital and non-digital industries, respectively.

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}} = \begin{matrix} \boxed{\begin{bmatrix} v_1b_{11}y_1 & v_1b_{12}y_2 \end{bmatrix}} \\ \begin{bmatrix} v_2b_{21}y_1 & v_2b_{22}y_2 \end{bmatrix} \end{matrix} \text{ GDP of digital industry}$$

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}} = \begin{matrix} \begin{bmatrix} v_1b_{11}y_1 & v_1b_{12}y_2 \end{bmatrix} \\ \boxed{\begin{bmatrix} v_2b_{21}y_1 & v_2b_{22}y_2 \end{bmatrix}} \end{matrix} \text{ GDP of non-digital industry}$$

In measuring the digital economy, the entirety of the digital industry's GDP must be obtained. The term $v_1b_{11}y_1$ accounts for the value-added required by the digital industry itself, which also happens to be its contribution to the value of its own final products. The second term, $v_1b_{12}y_2$, is the value-added which originated from the digital industry that is required by the non-digital industry. This also happens to be the contribution of the digital industry to the value of the non-digital industry's final products. Assuming that $v_1b_{12}y_2$ is nonzero, even if the second industry does not produce digital goods and services, its production is "enabled" by the digital industry[27] (In this sense, industry 2 through forward linkage is digitally-enabled).

However, it is apparent in the first column that the value of the digital industry's final goods and services may be comprised not only of contributions from itself ($v_1b_{11}y_1$) but also from the non-digital industry ($v_2b_{21}y_1$). Assuming that $v_2b_{21}y_1$ is nonzero, it is evident that the non-digital industry enables the production of the digital industry (In this sense, industry 2 through backward linkage is digitally-enabling). For this reason, $v_2b_{21}y_1$ will also be counted as part of the digital economy. The term $v_2b_{22}y_2$, on the other hand, pertains to value-added that originated from and is used by the non-digital industry.

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[27] One can say that a portion of the digital industry's value-added goes to the non-digital industry.

Since this does not involve transactions with the digital industry, it will not be counted as part of the digital economy.

Thus, the GDP attributable to the digital economy is given by the entire GDP of the digital industry plus the portion of the non-digital industry's GDP which enables the digital industry:

$$\mathrm{GDP_{digital}} = \mathrm{GDP_1} + \mathrm{GDP_2} - \mathrm{v_2 b_{22} y_2}$$

$$\mathrm{GDP_{digital}} = \mathrm{v_1 b_{11} y_1} + \mathrm{v_1 b_{12} y_2} + \mathrm{v_2 b_{21} y_1}$$

This can be directly computed using the equation below:

$$\mathrm{GDP_{digital}} = \mathbf{i}^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\boldsymbol{\varepsilon}_1 + \mathbf{i}^{\mathrm{T}}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})^{\mathrm{T}}\boldsymbol{\varepsilon}_1 - [\mathrm{diag}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})]^{\mathrm{T}}\boldsymbol{\varepsilon}_1 \tag{8}$$

$$= (1 \quad 1)\begin{bmatrix} \mathrm{v_1 b_{11} y_1} & \mathrm{v_1 b_{12} y_2} \\ \mathrm{v_2 b_{21} y_1} & \mathrm{v_2 b_{22} y_2} \end{bmatrix}\begin{pmatrix}1\\0\end{pmatrix} + (1 \quad 1)\begin{bmatrix} \mathrm{v_1 b_{11} y_1} & \mathrm{v_2 b_{21} y_1} \\ \mathrm{v_1 b_{12} y_2} & \mathrm{v_2 b_{22} y_2} \end{bmatrix}\begin{pmatrix}1\\0\end{pmatrix} - \begin{pmatrix} \mathrm{v_1 b_{11} y_1} \\ \mathrm{v_2 b_{22} y_2} \end{pmatrix}^{\mathrm{T}}\begin{pmatrix}1\\0\end{pmatrix}$$

$$= (\mathrm{v_1 b_{11} y_1} + \mathrm{v_2 b_{21} y_1} \quad \mathrm{v_1 b_{12} y_2} + \mathrm{v_2 b_{22} y_2})\begin{pmatrix}1\\0\end{pmatrix} + (\mathrm{v_1 b_{11} y_1} + \mathrm{v_1 b_{12} y_2} \quad \mathrm{v_2 b_{21} y_1} + \mathrm{v_2 b_{22} y_2})\begin{pmatrix}1\\0\end{pmatrix} - (\mathrm{v_1 b_{11} y_1} \quad \mathrm{v_2 b_{22} y_2})\begin{pmatrix}1\\0\end{pmatrix}$$

$$= \mathrm{v_1 b_{11} y_1} + \mathrm{v_2 b_{21} y_1} + \mathrm{v_1 b_{11} y_1} + \mathrm{v_1 b_{12} y_2} - \mathrm{v_1 b_{11} y_1}$$

$$= \mathrm{v_1 b_{11} y_1} + \mathrm{v_1 b_{12} y_2} + \mathrm{v_2 b_{21} y_1}$$

The first term, $\mathbf{i}^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\boldsymbol{\varepsilon}_1$, of Equation (8) directly calculates the backward linkage related to the digital industry while the second term, $\mathbf{i}^{\mathrm{T}}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})^{\mathrm{T}}\boldsymbol{\varepsilon}_1$, gives the forward linkage. To account for the double-counted term, the diagonal entry in the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix that corresponds to the digital industry is removed, which is why $[\mathrm{diag}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})]^{\mathrm{T}}\boldsymbol{\varepsilon}_1$ is subtracted in $\mathrm{GDP_{digital}}$. An "eliminator vector" $\boldsymbol{\varepsilon}_1$ is used to mathematically "eliminate" entries that should not be included in calculations. Such *eliminator vectors* will be used throughout the Framework.

Quantifying the digital economy in a simple three-industry economy without capital formation

Implementing the same method in the example above results in double counting if there are two or more digital industries that interact with each other. To demonstrate, let there be three industries in an economy, represented by the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix below.

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}} = \begin{bmatrix} \mathrm{v_1 b_{11} y_1} & \mathrm{v_1 b_{12} y_2} & \mathrm{v_1 b_{13} y_3} \\ \mathrm{v_2 b_{21} y_1} & \mathrm{v_2 b_{22} y_2} & \mathrm{v_2 b_{23} y_3} \\ \mathrm{v_3 b_{31} y_1} & \mathrm{v_3 b_{32} y_2} & \mathrm{v_3 b_{33} y_3} \end{bmatrix}$$

Assume that industries 1 and 2 are digital. Applying Equation (8), $\mathrm{GDP_{digital}}$ is expanded as a linear equation below.

$$\mathrm{GDP_{digital}} = \mathbf{i}^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\boldsymbol{\varepsilon} + \mathbf{i}^{\mathrm{T}}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})^{\mathrm{T}}\boldsymbol{\varepsilon} - [\mathrm{diag}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})]^{\mathrm{T}}\boldsymbol{\varepsilon}$$

$$\mathrm{GDP}_{\mathrm{digital}} = \mathrm{v}_1\mathrm{b}_{11}\mathrm{y}_1 + \mathrm{v}_2\mathrm{b}_{21}\mathrm{y}_1 + \mathrm{v}_3\mathrm{b}_{31}\mathrm{y}_1 + \mathrm{v}_1\mathrm{b}_{12}\mathrm{y}_2 + \mathrm{v}_2\mathrm{b}_{22}\mathrm{y}_2 + \mathrm{v}_3\mathrm{b}_{32}\mathrm{y}_2 + \mathrm{v}_1\mathrm{b}_{12}\mathrm{y}_2 + \mathrm{v}_1\mathrm{b}_{13}\mathrm{y}_3 + \mathrm{v}_2\mathrm{b}_{21}\mathrm{y}_1 + \mathrm{v}_2\mathrm{b}_{23}\mathrm{y}_3$$

As seen above, the terms, $\mathrm{v}_2\mathrm{b}_{21}\mathrm{y}_1$ and $\mathrm{v}_1\mathrm{b}_{12}\mathrm{y}_2$ are double counted since all value-added use of and value-added contribution to all digital industries in the economy are recorded. For example, $\mathrm{v}_2\mathrm{b}_{21}\mathrm{y}_1$, is the value-added generated by industry 2, which is used by industry 1 and is therefore counted from a forward perspective. However, this also happens to be a source of value-added for industry 1's final products and is then counted from a backward perspective.

From here, further adjustments are made in the framework to account for the interdependence of digital industries. A neat and simple solution is by aggregating similarly classified industries and treating them as a single sector, i.e., "digital sector," since the two-industry case reveals that the $\mathrm{GDP}_{\mathrm{digital}}$ equation precludes any double counting when there is only a single digital industry.

In the Framework, carrying out aggregations for the $\mathbf{Z}$, $\mathbf{x}$, $\mathbf{f}$, and $\mathbf{gva}$ matrices makes use of "aggregator matrices." The full demonstration of how these matrices work can be found in Appendix 2. Therefore, after aggregating digital sub-sectors into one digital sector, the procedure in the two-industry case is still preserved, except that aggregator matrices are integrated into the framework. Thus, only some notational changes are necessary given by the following:

$$\mathbf{x}_{\mathrm{agg}} = \mathbf{Z}_{\mathrm{agg}}\mathbf{i} + \mathbf{y}_{\mathrm{agg}}$$

$$\mathbf{x}_{\mathrm{agg}} = \left(\mathbf{I} - \mathbf{A}_{\mathrm{agg}}\right)^{-1}\mathbf{y}_{\mathrm{agg}}$$

$$\left(\mathbf{I} - \mathbf{A}_{\mathrm{agg}}\right)^{-1} \equiv \mathbf{B}_{\mathrm{agg}}$$

$$\mathbf{v}_{\mathrm{agg}} = (\mathrm{v}_1 \quad \mathrm{v}_2 \quad \cdots \quad \mathrm{v}_{n-q-1})$$

Integrating these notational changes with Equation 8 results in the revised $\mathrm{GDP}_{\mathrm{digital}}$ equation in Equation 9.

$$\mathrm{GDP}_i = \mathrm{v}_i\mathrm{b}_{i1}\mathrm{y}_1 + \mathrm{v}_i\mathrm{b}_{i2}\mathrm{y}_2 + \cdots + \mathrm{v}_i\mathrm{b}_{i,n-q-1}\mathrm{y}_{n-q-1}, \quad i = 1,2,\ldots n-q-1$$

$$\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}} = \begin{bmatrix} \mathrm{v}_1\mathrm{b}_{11}\mathrm{y}_1 & \mathrm{v}_1\mathrm{b}_{12}\mathrm{y}_2 & \cdots & \mathrm{v}_1\mathrm{b}_{1,\mathrm{n-q-1}}\mathrm{y}_{n-q-1} \\ \mathrm{v}_2\mathrm{b}_{21}\mathrm{y}_1 & \mathrm{v}_2\mathrm{b}_{22}\mathrm{y}_2 & \cdots & \mathrm{v}_2\mathrm{b}_{2,n-q-1}\mathrm{y}_{\mathrm{n}-q-1} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{v}_{n-q-1}\mathrm{b}_{n-q-1,1}\mathrm{y}_1 & \mathrm{v}_{n-q-1}\mathrm{b}_{n-q-1,2}\mathrm{y}_2 & \cdots & \mathrm{v}_{n-q-1}\mathrm{b}_{n-q-1,n-q-1}\mathrm{y}_{n-q-1} \end{bmatrix}$$

$$\mathrm{GDP}_{\mathrm{digital}} = \mathbf{i}^{\mathrm{T}}\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}}\boldsymbol{\varepsilon}_1 + \mathbf{i}^{\mathrm{T}}\left(\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}}\right)^{\mathrm{T}}\boldsymbol{\varepsilon}_1 - \left[\mathrm{diag}\left(\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}}\right)\right]^{\mathrm{T}}\boldsymbol{\varepsilon}_1 \tag{9}$$

Integrating gross fixed capital formation of the digital economy in a three-industry economy

Equation 9 captures all contemporaneous input-output transactions with respect to exogenous final demand. However, if in the current year an industry purchases capital goods[28] from a non-digital industry to use as inputs for future production, the $\mathbf{Z}$ matrix will not be able to capture this, as formation of fixed capital is reflected in the final demand vector, $\mathbf{y}$.

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[28] Capital goods refer to fixed assets, or assets intended for use in the production of other goods and services for a period of more than one year, as defined by the System of National Accounts (SNA) 2008.

While the contribution of fixed capital formation to current year's production is reflected in the $\mathbf{gva}$ matrix as *consumption of fixed capital*, it fails to account for the various sectoral contribution required to produce said fixed capital as an output in the market. To illustrate, suppose there is a three-industry economy with industry 1 as a digital industry and industry 2 and 3 as non-digital. Suppose further that industry 1 purchases capital goods from industry 3. In a standard input-output framework, this purchase by industry 1 will be reflected in $\mathbf{y}$. To show this, if $\mathbf{y}$ is disaggregated across three final demand components, for simplicity: household final consumption expenditure (hfce), general government consumption expenditure (ggce), and gross fixed capital formation (gfcf), then:

$$\mathbf{y} = \begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \mathbf{h} + \mathbf{g} + \mathbf{k} = \begin{bmatrix} \mathrm{hfce}_1 \\ \mathrm{hfce}_2 \\ \mathrm{hfce}_3 \end{bmatrix} + \begin{bmatrix} \mathrm{ggce}_1 \\ \mathrm{ggce}_2 \\ \mathrm{ggce}_3 \end{bmatrix} + \begin{bmatrix} \mathrm{gfcf}_1 \\ \mathrm{gfcf}_2 \\ \mathrm{gfcf}_3 \end{bmatrix}$$

Further disaggregating vector $\mathbf{k}$ into a matrix with columns as the purchaser of capital and the rows as the seller of capital results in matrix $\mathbf{K}$, where industry 1's purchase of fixed capital from industry 3 is equal to gfcf_{31}. Suppose gfcf_{31} is the only capital investment in the economy for the period.

$$\mathbf{K} = \begin{bmatrix} \mathrm{gfcf}_{11} & \mathrm{gfcf}_{12} & \mathrm{gfcf}_{13} \\ \mathrm{gfcf}_{21} & \mathrm{gfcf}_{22} & \mathrm{gfcf}_{23} \\ \mathrm{gfcf}_{31} & \mathrm{gfcf}_{32} & \mathrm{gfcf}_{33} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ \mathrm{gfcf}_{31} & 0 & 0 \end{bmatrix}$$

While matrix $\mathbf{K}$ shows which industry sold the capital, it does not show how said capital was produced. Therefore, without explicitly integrating the production of gross fixed capital purchased by digital industry 1, the computation of $\mathrm{GDP}_{\mathrm{digital}}$ will be understated. This is because the capital goods produced by industry 3 and purchased by industry 1 also derived value from other industries in the economy. Thus, other industries' value-added shares to industry 3's final products indirectly enable the digital economy and should therefore be counted as part of $\mathrm{GDP}_{\mathrm{digital}}$. The $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ matrix already contains this information, but it still needs to be explicitly augmented to Equation 9.

To derive an equation that accounts for the backward linkage of fixed capital goods consumed by the digital industry (i.e., the GDP contribution of digitally-enabling industries through capital formation), a single ratio[29] for each of the columns corresponding to industries from which the digital sector purchased capital goods can be applied.

In the previous illustration, multiplying the final product of industry 3, $v_1b_{13}y_3 + v_2b_{23}y_3 + v_3b_{33}y_3$, with a ratio, say r_3, will give the value of fixed capital investment by industry 1, gfcf_{31}. Let $\mathbf{r}$ be the vector of ratios of gfcf used by the digital industry to corresponding final demand and $\hat{\mathbf{r}}$ be the diagonalized $\mathbf{r}$.

$$\mathbf{r} = \begin{bmatrix} r_1 \\ r_2 \\ r_3 \end{bmatrix}; \quad \hat{\mathbf{r}} = \begin{bmatrix} r_1 & 0 & 0 \\ 0 & r_2 & 0 \\ 0 & 0 & r_3 \end{bmatrix}$$

Post-multiplying $\hat{\mathbf{r}}$ to $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}$ gives:

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[29] A single ratio would suffice given technical coefficients are assumed to be fixed, following the Leontief insight (Leontief, 1936).

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \begin{bmatrix} v_1b_{11}y_1 & v_1b_{12}y_2 & v_1b_{13}y_3 \\ v_2b_{21}y_1 & v_2b_{22}y_2 & v_2b_{23}y_3 \\ v_3b_{31}y_1 & v_3b_{32}y_2 & v_3b_{33}y_3 \end{bmatrix} \begin{bmatrix} r_1 & 0 & 0 \\ 0 & r_2 & 0 \\ 0 & 0 & r_3 \end{bmatrix} = \begin{bmatrix} r_1v_1b_{11}y_1 & r_2v_1b_{12}y_2 & r_3v_1b_{13}y_3 \\ r_1v_2b_{21}y_1 & r_2v_2b_{22}y_2 & r_3v_2b_{23}y_3 \\ r_1v_3b_{31}y_1 & r_2v_3b_{32}y_2 & r_3v_3b_{33}y_3 \end{bmatrix}$$

All elements in the first row and column of the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}$ matrix will already be accounted for by Equation 9 within forward and backward linkages, respectively, of the digital industry 1. To prevent double counting of a portion of the forward linkage of the digital industry in $\mathrm{GDP}_{\mathrm{digital}}$, $(\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}$ is pre-multiplied to $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}$:

$$(\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \begin{pmatrix} 0 & 1 & 1 \end{pmatrix} \begin{bmatrix} v_1b_{11}y_1 & v_1b_{12}y_2 & v_1b_{13}y_3 \\ v_2b_{21}y_1 & v_2b_{22}y_2 & v_2b_{23}y_3 \\ v_3b_{31}y_1 & v_3b_{32}y_2 & v_3b_{33}y_3 \end{bmatrix} \begin{bmatrix} r_1 & 0 & 0 \\ 0 & r_2 & 0 \\ 0 & 0 & r_3 \end{bmatrix}$$

$$\rightarrow (\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \left(\sum_{i \neq 1}^{3} \mathrm{vby}_{i1} \quad \sum_{i \neq 1}^{3} \mathrm{vby}_{i2} \quad \sum_{i \neq 1}^{3} \mathrm{vby}_{i3} \right) \begin{bmatrix} r_1 & 0 & 0 \\ 0 & r_2 & 0 \\ 0 & 0 & r_3 \end{bmatrix}$$

$$\rightarrow (\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \left(r_1 \sum_{i \neq 1}^{3} \mathrm{vby}_{i1} \quad r_2 \sum_{i \neq 1}^{3} \mathrm{vby}_{i2} \quad r_3 \sum_{i \neq 1}^{3} \mathrm{vby}_{i3} \right)$$

Since industry 1 only invests in final products of industry 3, r_2 will be equal to zero, which leaves the following:

$$(\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \left(r_1 \sum_{i \neq 1}^{3} \mathrm{vby}_{i1} \quad 0 \quad r_3 \sum_{\mathrm{i} \neq 1}^{3} \mathrm{vby}_{i3} \right)$$

Another eliminator vector, $\boldsymbol{\varepsilon}_2 = \begin{pmatrix} 0 & 0 & 1 \end{pmatrix}^{\mathrm{T}}$ is then post-multiplied to $(\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}$ to get: $(\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}\boldsymbol{\varepsilon}_2 = (\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} = \left(r_1 \sum_{i \neq 1}^{3} \mathrm{vby}_{i1} \quad 0 \quad r_3 \sum_{i \neq 1}^{3} \mathrm{vby}_{i3} \right) \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix}$

$$\rightarrow (\mathbf{i} - \boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}\boldsymbol{\varepsilon}_2 = r_3 \sum_{i \neq 1}^{3} \mathrm{vby}_{i3}$$

The eliminator vector $\boldsymbol{\varepsilon}_2$ has a value of 1 for the row corresponding to the industry from which the digital industry purchases fixed capital, except itself. Excluding own-account capital formation of the digital industry from the computation is required to prevent double counting of a portion of the backward linkage of the digital industry in $\mathrm{GDP}_{\mathrm{digital}}$. Therefore, in the illustration, the element of $\boldsymbol{\varepsilon}_2$ corresponding to digital industry, ε_{2_1}, is set to zero, as well as ε_{2_2}. Only $\varepsilon_{2_3} = 1$ because industry 1 only purchases fixed capital from industry 3. The term $r_3 \sum_{i \neq 1}^{3} \mathrm{vby}_{i3}$ corresponds to the backward linkage of fixed capital goods consumed by the digital industry 1 from non-digital industry 3.

Quantifying the digital economy in an $\boldsymbol{n}$-industry economy

The three-industry case is generalizable to an economy with n industries. To illustrate, the dimension of the vector of ratios, $\mathbf{r}$, is redefined to $n \times 1$. Correspondingly, this is diagonalized as $\hat{\mathbf{r}}$, to form an $n \times n$ matrix.

$$\mathbf{r} = \begin{bmatrix} r_1 \\ r_2 \\ \vdots \\ r_n \end{bmatrix}; \quad \hat{\mathbf{r}} = \begin{bmatrix} r_1 & 0 & 0 & 0 \\ 0 & r_2 & 0 & 0 \\ 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & r_n \end{bmatrix}$$

Likewise, the $\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}$ matrix will have a dimension of $n \times n$, as shown below.

$$\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \begin{bmatrix} \mathrm{v}_1\mathrm{b}_{11}\mathrm{y}_1 & \mathrm{v}_1\mathrm{b}_{12}\mathrm{y}_2 & \cdots & \mathrm{v}_1\mathrm{b}_{1j}\mathrm{y}_j & \cdots & \mathrm{v}_1\mathrm{b}_{1n}\mathrm{y}_n \\ \mathrm{v}_2\mathrm{b}_{21}\mathrm{y}_1 & \mathrm{v}_2\mathrm{b}_{22}\mathrm{y}_2 & \cdots & \mathrm{v}_2\mathrm{b}_{2j}\mathrm{y}_j & \cdots & \mathrm{v}_2\mathrm{b}_{2n}\mathrm{y}_n \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathrm{v}_j\mathrm{b}_{j1}\mathrm{y}_1 & \mathrm{v}_j\mathrm{b}_{j2}\mathrm{y}_2 & \cdots & \mathrm{v}_j\mathrm{b}_{jj}\mathrm{y}_j & \cdots & \mathrm{v}_j\mathrm{b}_{jn}\mathrm{y}_n \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathrm{v}_n\mathrm{b}_{n1}\mathrm{y}_1 & \mathrm{v}_n\mathrm{b}_{n2}\mathrm{y}_2 & \cdots & \mathrm{v}_n\mathrm{b}_{nj}\mathrm{y}_j & \cdots & \mathrm{v}_n\mathrm{b}_{nn}\mathrm{y}_n \end{bmatrix} \begin{bmatrix} \mathrm{r}_1 & 0 & 0 & 0 & 0 & 0 \\ 0 & \mathrm{r}_2 & 0 & 0 & 0 & 0 \\ 0 & 0 & \ddots & 0 & 0 & 0 \\ 0 & 0 & 0 & \mathrm{r}_j & 0 & 0 \\ 0 & 0 & 0 & 0 & \ddots & 0 \\ 0 & 0 & 0 & 0 & 0 & \mathrm{r}_n \end{bmatrix}$$

$$= \begin{bmatrix} \mathrm{r}_1\mathrm{v}_1\mathrm{b}_{11}\mathrm{y}_1 & \mathrm{r}_2\mathrm{v}_1\mathrm{b}_{12}\mathrm{y}_2 & \cdots & \mathrm{r}_j\mathrm{v}_1\mathrm{b}_{1j}\mathrm{y}_j & \cdots & \mathrm{r}_n\mathrm{v}_1\mathrm{b}_{1n}\mathrm{y}_n \\ \mathrm{r}_1\mathrm{v}_2\mathrm{b}_{21}\mathrm{y}_1 & \mathrm{r}_2\mathrm{v}_2\mathrm{b}_{22}\mathrm{y}_2 & \cdots & \mathrm{r}_j\mathrm{v}_2\mathrm{b}_{2j}\mathrm{y}_j & \cdots & \mathrm{r}_n\mathrm{v}_2\mathrm{b}_{2n}\mathrm{y}_n \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathrm{r}_1\mathrm{v}_j\mathrm{b}_{j1}\mathrm{y}_1 & \mathrm{r}_2\mathrm{v}_j\mathrm{b}_{j2}\mathrm{y}_2 & \cdots & \mathrm{r}_j\mathrm{v}_j\mathrm{b}_{jj}\mathrm{y}_j & \cdots & \mathrm{r}_n\mathrm{v}_j\mathrm{b}_{jn}\mathrm{y}_n \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \mathrm{r}_1\mathrm{v}_n\mathrm{b}_{n1}\mathrm{y}_1 & \mathrm{r}_2\mathrm{v}_n\mathrm{b}_{n2}\mathrm{y}_2 & \cdots & \mathrm{r}_j\mathrm{v}_n\mathrm{b}_{nj}\mathrm{y}_j & \cdots & \mathrm{r}_n\mathrm{v}_n\mathrm{b}_{nn}\mathrm{y}_n \end{bmatrix}$$

Now, suppose industry 1 is a digital industry and that it purchases fixed capital from both industry j and itself. Assume that only industry 1 is digital, while the rest of the $n-1$ industries are non-digital. The $(\mathbf{i}-\boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}$ equation becomes

$$(\mathbf{i}-\boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \left(\mathrm{r}_1\sum_{i\neq 1}^{n}\mathrm{vby}_{i1} \quad \mathrm{r}_2\sum_{i\neq 1}^{n}\mathrm{vby}_{i2} \quad \cdots \quad \mathrm{r}_j\sum_{i\neq 1}^{n}\mathrm{vby}_{ij} \quad \cdots \quad \mathrm{r}_n\sum_{i\neq 1}^{n}\mathrm{vby}_{in}\right)$$

$$\rightarrow (\mathbf{i}-\boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}} = \left(\mathrm{r}_1\sum_{i\neq 1}^{n}\mathrm{vby}_{i1} \quad 0 \quad \cdots \quad \mathrm{r}_j\sum_{i\neq 1}^{n}\mathrm{vby}_{ij} \quad \cdots \quad 0\right)$$

To eliminate the double counting of the backward linkage of own-account fixed capital formation in the digital industry, the $n \times 1$ eliminator vector $\boldsymbol{\varepsilon}_2$ is post-multiplied to $(\mathbf{i}-\boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}$ to arrive at a value for the backward linkage of fixed capital goods consumed by the digital industry.

$$(\mathbf{i}-\boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}\boldsymbol{\varepsilon}_2 = \left(\mathrm{r}_1\sum_{i\neq 1}^{n}\mathrm{vby}_{i1} \quad 0 \quad \cdots \quad \mathrm{r}_j\sum_{i\neq 1}^{n}\mathrm{vby}_{ij} \quad \cdots \quad 0\right)\begin{pmatrix} 0 \\ 0 \\ \vdots \\ 1 \\ \vdots \\ 0 \end{pmatrix}$$

The Core Digital Economy Equation

The core digital economy equation (Equation 10) is derived by consolidating Equation 9 with the value of the backward linkage of fixed capital goods consumed by the digital industry. In Equation 10, the "agg" subscripts are suppressed for notational simplicity but note that aggregation, as discussed in Section 4.4 and Appendix 2, was done prior to calculations.

$$\begin{aligned} \mathrm{GDP}_{\mathrm{digital}} = {} & \mathbf{i}^{\mathrm{T}}\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}}\boldsymbol{\varepsilon}_1 + \mathbf{i}^{\mathrm{T}}\left(\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}}\right)^{\mathrm{T}}\boldsymbol{\varepsilon}_1 - \left[\mathrm{diag}\left(\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}}\right)\right]^{\mathrm{T}}\boldsymbol{\varepsilon}_1 \\ & + (\mathbf{i}-\boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}_{\mathrm{agg}}\mathbf{B}_{\mathrm{agg}}\hat{\mathbf{y}}_{\mathrm{agg}}\boldsymbol{\varepsilon}_2 \end{aligned}$$

The "agg" subscripts are suppressed for notational simplicity but note that aggregation, as discussed in Section 4.4 and Appendix 2, was done prior to calculation

$$\mathrm{GDP}_{\mathrm{digital}} = \mathbf{i}^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\boldsymbol{\varepsilon}_1 + \mathbf{i}^{\mathrm{T}}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})^{\mathrm{T}}\boldsymbol{\varepsilon}_1 - [\mathrm{diag}(\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}})]^{\mathrm{T}}\boldsymbol{\varepsilon}_1 + (\mathbf{i}-\boldsymbol{\varepsilon}_1)^{\mathrm{T}}\hat{\mathbf{v}}\mathbf{B}\hat{\mathbf{y}}\hat{\mathbf{r}}\boldsymbol{\varepsilon}_2 \qquad (10)$$

In Equation 10, the four terms respectively refer to the digital economy's 1) backward linkages, 2) forward linkages, 3) the double counted term (i.e., the aggregate digital industry's value-added contribution to its own final goods), and 4) the non-digital products it capitalizes. These four terms are visually presented in Figure 1.

Methodological Requirements

Supply and Use Tables and Input-Output Tables

The principal sources of data for the digital economy framework are national Supply and Use tables (SUTs) and input-output tables (IOTs). On the one hand, the Supply table details how goods and services are supplied in the economy, either by domestic production or imports. On the other hand, the Use table demonstrates how these outputs are used in the economy, either as intermediate consumption, final consumption, capital formation, or exports. SUTs are the main bases for national economic accounting systems, as a dataset that describes interactions within an economy and as a balancing framework for GDP calculations. This makes it an attractive source for various kinds of analytical uses and satellite systems (United Nations, 2018).

The IOT combines the identities in the Supply table and in the Use table into a single identity (United Nations, 2018). As discussed in the previous sections, the proposed methodology requires matrices and vectors directly extracted from IOTs. SUTs may be easily transformed into IOTs using a transformation model prescribed in Eurostat (2008). For this paper, the *fixed product sales structure* assumption[30] was used to transform SUTs to IOTs, which converts a product-by-industry SUT to an industry-by-industry IOT.

While IOTs allow a more organized application of Leontief's insight in analyses, SUTs provide greater detail on dynamics between products and industries at the rudimentary level. Thus, SUTs are particularly useful to capture the fourth term in the central formula (Equation 10) which incorporates the digital sectors' dependence on fixed capital. They may also be used for analyses concerning specific product-industry relationships, such as in assessing the digitalization of industries based on the use of digital products.

Uniformity Across National Tables

To ensure consistency with published aggregates, SUTs and / or IOTs are sourced from the economies' published tables in its respective national statistics office (NSOs) websites. Oftentimes, this entails further data collection and adjustment to apply the methodology as uniformly as possible across different economies. Three main concerns are considered to ensure uniformaity and comparability of data: correspondence in classification systems, harmonization of SUT and IOT presentation format, and comparability in price and valuation.

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[30] Known as "Model D," this assumes that each product has its own specific sales structure, irrespective of the industry where it is produced (Eurostat, 2008).

Correspondence in classification systems

One major point of consideration is that different product and industry classification systems may be adopted by different economies. As such, identifying the exact same digital products and industries across economies requires a close inspection and harmonization of these classification system. For example, Canada uses the North American Industry Classification System (NAICS) while Singapore uses its own Singapore Standard Industries Classification. Ensuring comparability between estimates of Canada's and Singapore's digital economy requires an accurate correspondence between two different classification systems.

Another consideration is the varying levels of disaggregation of product and industry classification in SUTs or IOTs. Even when two economies adopt the same classification system, further data manipulation is necessary when disaggregation levels are not the same.

Harmonization of SUT and IOT presentation format

Another main concern is possible differences in the format by which tables are presented per economy. While presentation format, in general, do not pose any real issue, problems arise when the variance pertains to difference in values contained in the $\mathbf{Z}$ matrix and $\mathbf{y}$ vector. For example, in the case of Japan, competitive imports are included in the intermediate consumption matrix. In the Framework, the $\mathbf{Z}$ matrix only includes domestic output. Thus, appropriate adjustments must be made in such cases.

Comparability in price and valuation

Values in SUTs and IOTs may also be expressed in different prices (i.e., current prices or constant prices) and / or in different valuation (i.e., basic prices, producer's prices, or purchaser's prices). Tables at current prices are the bases of the main estimates produced by the Framework. However, tables at constant prices are also employed when temporal analyses are made, such that only real changes are measured.

Furthermore, *assuming* that the same economy and year and assuming taxes, subsidies, and trade and transport margins are proportionately distributed across the products in the economy, estimates of $\mathrm{GDP}_{\mathrm{digital}}$ as a percentage of GDP calculated using tables valued in either basic, producer's, or purchaser's prices should not significantly differ from each other. Otherwise, when comparing across economies or across time, it is preferred that the tables follow the same valuation.

The aforementioned are the most common differences observed across national tables. However, others may be encountered and should be appropriately addressed, especially when the inconsistency has a pervasive effect on the estimates. As long as the same methodology is applied given the available data, overall results per economy may be used for comparative analyses.

Disaggregating Products and Industries

Given the varying levels of product and industry disaggregation that economies present their SUTs and IOTs, it is necessary to conduct a thorough evaluation of product and industry classification and then appropriately disaggregate the data. This poses a key challenge for tables with less than the desired level of detail, for which isolation of the exact digital activities identified for this methodology is crucial. As an example, software publishing is often combined with all publishing activities, and this needs to be extracted from other non-digital publishing activities.

Consing et al., 2020, which employs the same theoretical framework, studied and compared several data sources based on merits and drawbacks as a basis for disaggregation. Table 2 lists the established ranking of the top sources of data, from highest to lowest in terms of degree of reliability.

Table 2: Data Sources for Disaggregating Sectors

Source of data	Merits	Drawbacks and/or caveats
National statistics office	Highly reliable data consistent with the construction of SUT	Dependent on public availability of data or the NSO's responsiveness to queries
Relevant journals and published reports	Alternative of sourcing out if primary data is not available	Finding consistent and reliable data may be time-consuming, if even available
Supply table	Readily available in the SUT	Applies only if the desired degree of disaggregation among sectors is present
Operating revenue data from credible data resources	Readily available given permissions to access certain databases	May be limited by the amount of data collected by the resource
Data from donor economy	Basis on an actual economy's industry disaggregation	Requires some degree of similarity in terms of structure between the 2 economies
Number of establishments from credible data resources	Readily available given permissions to access certain databases	Bias from an assumption of homogeneity

Source: R. Consing, M. Barsabal, J. Alvarez, M. Mariasingham. 2020. The Wellness Economy, A Comprehensive System of National Accounts Approach

Using the best data disaggregation source available, a disaggregation ratio is calculated as the proportion of estimated digital activity (output) from the aggregate industry activity (output). The resulting percentage is then multiplied to all values in both the row and the column corresponding to the particular aggregate industry in the IOT. In effect, two sub-industries replace the aggregate industry, expanding the dimension of the original IOT, but without changing its total measures and symmetry.

To illustrate, suppose there is the following 2 × 2 IOT:

	Industry 1	Industry 2	FD	Gross Output
Industry 1	z_{11}	z_{12}	f_1	x_1
Industry 2	z_{21}	z_{22}	f_2	x_2
GVA	gva_1	gva_2		
Gross Output	x_1	x_2		

Suppose further that Industry 1 is an aggregate sector that contains both digital and non-digital sub-sectors. Therefore, it is necessary to disaggregate Industry 1 into 2 sub-industries. Given the following revenue shares, derived from credible sources:

α which stands for the share of digital sub-industry 1a to Industry 1's total revenue, and

β which stands for the share of non-digital sub-industry 1b to Industry 1's total revenue.

where $\alpha + \beta = 1$, a disaggregated 3 × 3 IOT is obtained as follows:

	Industry 1a	**Industry 1b**	**Industry 2**	**FD**	**Output**
Industry 1a	$\alpha\alpha z_{11}$	$\alpha\beta z_{11}$	αz_{12}	αf_1	αx_1
Industry 1b	$\beta\alpha z_{11}$	$\beta\beta z_{11}$	βz_{12}	βf_1	βx_1
Industry 2	αz_{21}	βz_{21}	z_{22}	f_2	x_2
GVA	αgva_1	βgva_1	gva_2		
Output	αx_1	βx_1	x_2		

Several checks have to be implimented to ensure the accuracy of disaggregation. First, the resulting 3 × 3 IOT should be symmetric with respect to its gross output, as the original 2 × 2 IOT. Second, total gross output must be exactly the same for the two tables[31]. Last, the sum of the technical coefficients for Industry 1a and 1b should be the same as the technical coefficient of aggregate Industry 1[32]. Note that this disaggregation method can be extended to an n-industry setting.

Construction of the MRIO with Digital Sectors

When measuring international linkages, particularly GVCs in the context of the digital economy, credible regional or inter-economy IOTs should be used instead of individual national IOTs. One useful resource in conducting such analyses is the Asian Development Bank Multi-Regional Input-Output Table (ADB MRIO). However, the main hurdle prior to conducting any GVC analyses for the digital economy is the aggregation level of the ADB MRIO. As such, one of the key efforts of this project is the construction of the ADB MRIO with industries disaggregated up to the level required in the Framework.

The ADB MRIO database contains information on the production, consumption, and trade linkages of 63 economies, including an aggregated economy for Rest of the World (RoW). Each MRIO economy has 35 sectors[33] and five final demand components[34]. The ADB MRIO generally follows the sources and method to construct the World Input Output Database (WIOD), handled by the University of Groningen[35].

The ADB MRIO sectors Electrical and Optical Equipment (c14), Post and Telecommunications (c27), and Renting of M&Eq and Other Business Activities (c30) include the digital sectors identified in the Framework, and were therefore split into two sub-sectors each to isolate the digital sub-sectors. Thus, instead of the usual 35 sectors, this paper uses a 38-sector ADB MRIO for years 2017-2019. **Error! Reference source not found.** shows the 6 new sectors as a result of isolating digital industries. For the MRIO, the authors had to disaggregate the 3 sectors for each of the 62 economies (Figure 3).

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[31] To show that gross output is the same for the 2 × 2 and 3 × 3 IOTs:
$x_1 + x_2 = \alpha x_1 + \beta x_1 + x_2 \Rightarrow x_1 + x_2 = (\alpha + \beta) x_1 + x_2 \Rightarrow x_1 + x_2 = x_1 + x_2$ ■

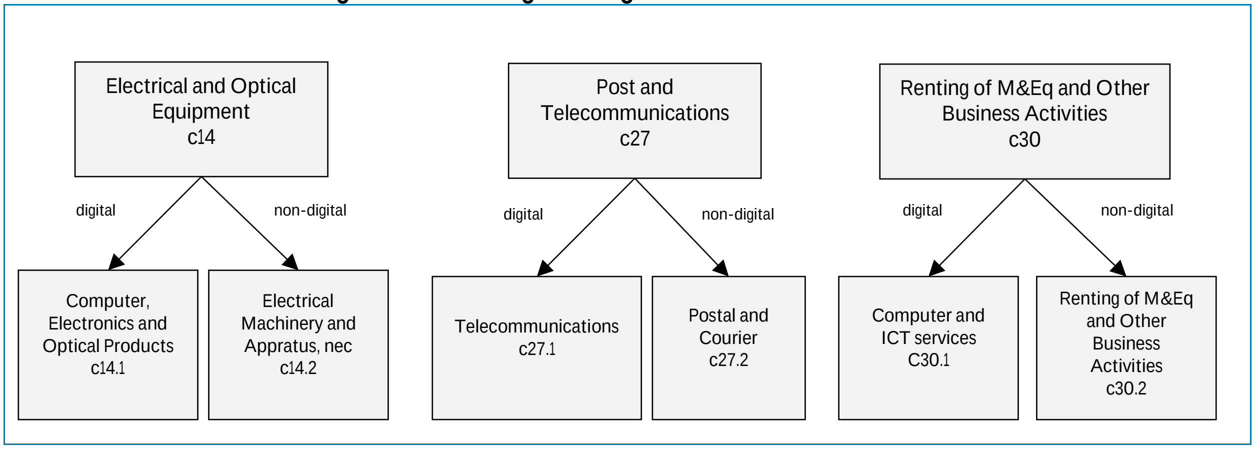
[32] To show that the sum of technical coefficients of Industries 1a and 1b is equal to the technical coefficient of Industry 1:
$\frac{z_{11}}{x_1} = \frac{\alpha\alpha z_{11}}{\alpha x_1} + \frac{\beta\alpha z_{11}}{\alpha x_1} = \frac{\alpha\beta z_{11}}{\beta x_1} + \frac{\beta\beta z_{11}}{\beta x_1} \Rightarrow \frac{z_{11}}{x_1} = \frac{\alpha z_{11}}{x_1} + \frac{\beta z_{11}}{x_1} \Rightarrow \frac{z_{11}}{x_1} = \frac{\alpha z_{11} + \beta z_{11}}{x_1} \Rightarrow \frac{z_{11}}{x_1} = \frac{(\alpha + \beta) z_{11}}{x_1} \Rightarrow \frac{z_{11}}{x_1} = \frac{z_{11}}{x_1}$ ■

[33] Appendix Table 3 outlines the 35 MRIO sectors.

[34] The five final demand components include household final consumption expenditure (FCE), non-profit institutions serving households (NPISH) FCE, government FCE, gross fixed capital formation, and changes in inventories.

[35] See Timmer et al. (2012) for details on constructing the WIOD.

Figure 2: Isolating the Digital Sectors in the MRIO

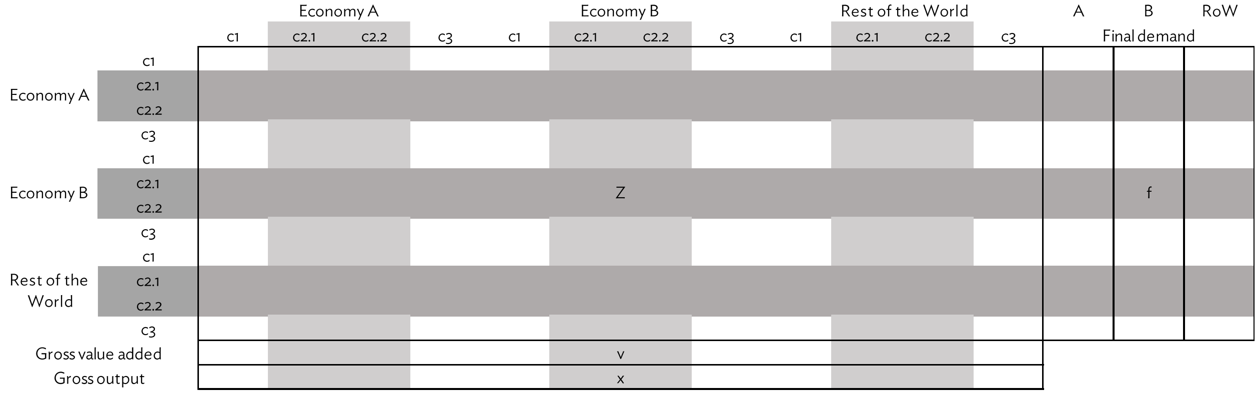


Source: Authors' methodology.

To isolate the digital component from c14, c27, and c30, column and row disaggregators were generated using multiple data sources. Column disaggregators gathered information from WIOD and national SUTs to disaggregate the digital component in gross output, GVA, and imported inputs. Digital component for intermediate consumption and domestic inputs were computed as a residual. Meanwhile, row disaggregators made use of bilateral exports and imports data by Broad Economic Categories (BEC) classification[36] from UN Comtrade. These information were converted into shares which were consequently used to split the rows and columns of the ADB MRIO *63x35* tables into *63x38* tables. The authors then compared the resulting ADB MRIO table values with the published NSO numbers to ensure data consistency and checked whether the table is balanced or symmetric.

Figure 3: Illustration of the MRIO Disaggregation Process

Disaggregating the c2 sector



Note: **Z** = intermediate consumption matrix, **v** = value-added vector, **x** = gross output vector, and **f** = final demand matrix
Source: Authors' methodology.

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[36] The broad economic catergories fall under intermediated use, final consumption, or capital goods.

Framework Limitations

The framework presented in this study aims to be entirely data-driven and based on economically and statistically sound approaches. Data collection and analysis mainly adopt a top-down strategy, relying on secondary data published by official and credible sources. As such, a range of data limitations arise from this. Firstly, the accessibility to granular data is often limited. Therefore, to disaggregate high-level data, direct inquiries to the appropriate national statistics offices is necessary, further supplemented by subordinate methods to extrapolate the required data. Where there is available data, format, structure, and statistical compilation methods used may vary widely per economy, thus requiring a significant amount of data cleaning and processing. Therefore, a constraint exists in ensuring consistency and accuracy of all data.

Secondly, exclusions from what are defined to be the digital economy may be interpreted as limitations in completeness. This framework considers the narrowest possible definition of digital products. For example, the entire value of an online sale of a non-digital commodity is not considered, but instead only the value contribution of the digital products (or the digital industries producing these) involved in such a transaction is captured.

Thirdly, the measurement framework, which estimates the value of the digital economy as a percentage of national GDP, presents another area of limitation. Since economy-wide GDP excludes imports, the digital economy estimates likewise exclude these. Furthermore, as the scope of digital products is at the narrowest level, it excludes the digitally-enabled economy, which comprises of the value-added of the sectors that are critically dependent on digital sectors. Therefore, economies that have high imports of digital products as well as those with industries heavily reliant on the core digital sectors (as defined in succeeding sections) are likely to have a small digital economy estimates relative to others. Supplementary analyses must be conducted for more expansive insights.

Finally, another limitation lies in the input-output model's assumption that production processes are fixed in the short-term or do not change within an accounting period. This ignores changes in production requirements that happen within one year, which is not an impossibility, given the fast-paced nature of digitalization and digital transformation.

References [37]

A. Amuno. 2017. *The Five Types of Systems Software*. https://turbofuture.com/computers/The-Five-Types-of-System-Software

A. Franklin. 2019. *Software 101: A Complete Guide To Different Types Of Software*. https://www.goodcore.co.uk/blog/types-of-software/

A. Fung. 2017. A History of Casette Tapes – Is that a Fossil? *Medium*. https://medium.com/@aaronnfung/a-history-of-cassette-tapes-is-that-a-fossil-760f40729333

A. Mauldin. 2017. *A Complete List of Content Providers' Submarine Cable Holdings*. Retrieved from Telegeography: https://blog.telegeography.com/telegeographys-content-providers-submarine-cable-holdings-list

A. Scupola. 2019. *Digital Transformation of Public Administration Services in Denmark: A Process Tracing Case Study*. https://www.riverpublishers.com/journal/journal_articles/RP_Journal_1902-097X_2018114.pdf

A. Sraders. 2020. *What Is Fintech? Uses and Examples in 2020*. https://www.thestreet.com/technology/what-is-fintech-14885154

Advisory Expert Group on National Accounts. 2019. 13th Meeting fo the Advisory Expert Group on National Accounts: Framework for a satellite account on the digital economy. Washington, D.C. https://unstats.un.org/unsd/nationalaccount/aeg/2019/M13.asp

Amazon. n.d. *What robots do (and don't do) at Amazon fulfilment centres*. https://www.aboutamazon.co.uk/amazon-fulfilment/what-robots-do-and-dont-do-at-amazon-fulfilment-centres

Asian Development Bank. 2020. *Asian Development Outlook Supplement: December 2020*. Mandaluyong City, Philippines: Asian Development Bank.

Autonomous Manufacturing. 2020. *40+ 3D Printing Industry Stats You Should Know*. https://amfg.ai/2020/01/14/40-3d-printing-industry-stats-you-should-know-2020-redirect/

B. Mitchell. 2019. *PSTN (Public Switched Telephone Network)*. https://www.lifewire.com/pstn-public-switched-telephone-network-818168

Bain & Company, Google and Temasek. 2020. *e-Conomy SEA 2020: At Full Velocity – Resilient and Racing Ahead.* Bain & Company, Google and Temasek. https://www.thinkwithgoogle.com.

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[37] Includes references for the final version of the supplement not cited here.

BBC. 2007. *Happy 20th birthday to the CD*. http://web.archive.org/web/20070219014205/http:/www.bbc.co.uk/skillswise/inthenews/numbers/0306.shtml

BBC. 2013. *Taiwan's struggle to become an innovation leader*. https://www.bbc.com/future/article/20130918-taiwans-rocky-road-to-innovation

BT. 2021. *About BT*. https://www.bt.com/about/bt

Bureau van Dijk. 2018. Orbis. https://orbis.bvdinfo.com/

C. Bean. 2016. *Independent Review of UK Economic Statistics*. HM Treasury.

C. Breisinger, M. Thomas, and J. Thurlow. 2010. Social Accounting Matrices and Multiplier Analysis: An Introduction with Exercises. IFPRI.

C. Corrado, Haskel, J., Jona-Lasinio, C., & Iommi, M. 2016. Intangible investment in the EU and US before and since the Great Recession and its contribution to productivity growth. *EIB Working Papers, 8*.

C. Date. n.d. *Edgar F. ("Ted") Codd*. https://amturing.acm.org/award_winners/codd_1000892.cfm

C. Egeraat and D. Jacobson. 2004. *The Rise and Demise of the Irish and Scottish Computer Hardware Industry*. European Planning Studies, Vol. 12 (6).

C. Ravets. 2016, April. *The Internet Economy*. Retrieved April 20, 2021

China Academy of Information and Communication Technology. 2020. *Digital Economy Development in China*. http://www.caict.ac.cn/english/research/whitepapers/202007/P020200728343679920779.pdf

Computer History Museum. n.d. Timeline of Computer History. https://www.computerhistory.org/timeline/computers/

D. Burkett. 2017. *Digitisation and Digitalisation: What Means What?* https://workingmouse.com.au/innovation/digitisation-digitalisation-digital-transformation/

D. Nguyen & Paczos, M. 2020. *Measuring the Economic Value of Data and Cross-Border Data Flows: A Business Perspective*. Paris: OECD Publishing.

D. O'Boyle. 2020. *Danish igaming participation rate second-highest in Europe*. https://igamingbusiness.com/danish-online-market-continues-to-grow-to-dkk5-2bn-in-2019/

D. Shapardson and K. Freifield. 2019. Trump administration hits China's Huawei with one-two punch. https://www.reuters.com/article/us-usa-china-trump-telecommunications/trump-administration-hits-chinas-huawei-with-one-two-punch-idUSKCN1SL2QX. Accessed on 14 May 2021.

D. Sher. 2020. *This is how much additive manufacturing is worth in the top global AM markets*. https://www.3dprintingmedia.network/the-top-20-global-am-markets/

D. Tapscott. 1996. *The Digital Economy: Promise and Peril in the Age of Networked Intelligenc*e, McGraw-Hill, New York, NY.

D.J. Bertulfo, E. Gentile, and G.D. Vries. 2019. The employment effects of technological innovation, consumption, and participation in global value chains: Evidence from developing Asia. *Asian Development Bank Economics Working Paper Series*, (572).

E. Brynjolfsson, et al. 2019. *GDP-B: Accounting for the Value of New and Free Goods in the Digital Economy* (NBER Working Paper No. 25695). National Bureau of Economic Research.

E. Brynjolfsson & Steffenson. 2017. Data-driven decision making in action. *MIT IDE Research brief.*

E. Brynjolfsson & Collis, A. 2019, November. *How Should We Measure the Digital Economy*. Retrieved from Harvard Business Review: https://hbr.org/2019/11/how-should-we-measure-the-digital-economy

E. Byrnjolfsson, Collis, A., & Eggers, F. 2019. Using massive online choice experiments to measure changes in well-being. *Proceedings of the National Academy of Sciences*, *116*, pp. 7250-7255.

European Union. 2020. *The Digital Economy and Society Index*. https://ec.europa.eu/digital-single-market/en/digital-economy-and-society-index-desi

Eurostat. 2008. *The Eurostat Manual of Supply, Use and Input-Output Tables*. Luxembourg: Office for Official Publications of the European Communities.

F. de Nicola, J. Timmis, and A. Akhlaque. 2020. *How is COVID-19 Transforming Global Value Chains? Lessons from Ethiopia and Vietnam.* World Bank Blogs. https://blogs.worldbank.org

Facebook. 2020. *Facebook Reports Fourth Quarter and Full Year 2019 Results*. https://investor.fb.com/investor-news/press-release-details/2020/Facebook-Reports-Fourth-Quarter-and-Full-Year-2019-Results/default.aspx

Fiji Bureau of Statistics. 2014. Economic Surveys: *Information and Communication 2011*. https://www.statsfiji.gov.fj/

Fiji Bureau of Statistics. 2018. Economic Surveys: *Information and Communication 2015*. https://www.statsfiji.gov.fj/

Fortune Business Insights. 2021. *Industry 4.0 Market*. https://www.fortunebusinessinsights.com/industry-4-0-market-102375

G. Dhillon, et al. 2021. *Online Gambling in Malaysia: A Legal Analysis*. Universiti Putra Malaysia Press. https://doi.org/10.47836/pjssh.29.1.12

G. Graetz and G. Michaels. 2018. Robots at work. *Review of Economics and Statistics*, 100(5), 753-768.

G. Press. 2016. Forbes. *A Very Short History of Digitization*. https://www.forbes.com/sites/gilpress/2015/12/27/a-very-short-history-of-digitization/?sh=664d11d649ac

Global Industry Analysts, Inc. 2021. Global Artificial Intelligence (AI) Market to Reach $228.3 Billion by 2026. https://www.prnewswire.com/news-releases/global-artificial-intelligence-ai-market-to-reach-228-3-billion-by-2026--301293951.html

Hanzawa, S. 2019. *Geographical dynamics of the Japanese animation industry.* Networks and Communication Studies (33-3/4). DOI: https://doi.org/10.4000/netcom.4546

History. 2018. *Automated Teller Machines*. https://www.history.com/topics/inventions/automated-teller-machines

Huawei and Oxford Economics. 2017. *Digital Spillover: Measuring the true impact of the Digital Economy*. https://www.huawei.com/minisite/gci/en/digital-spillover/index.html

I. Bosilkovski. 2020. *Stanford Grad Who Created The World's First 'Robot Lawyer' Raises $12 Million In Series A*. https://www.forbes.com/sites/igorbosilkovski/2020/06/23/stanford-grad-who-created-the-worlds-first-robot-lawyer-raises-12-million-in-series-a/?sh=177a0e5e3309

I. King, D. Wu, and D. Pogkas. 2021. How a Chip Shortage Snarled Everything from Phones to Cars. *Bloomberg.* https://www.bloomberg.com/graphics/2021-semiconductors-chips-shortage/?sref=ExbtjcSG.

I. Süßmann. 2015. *German Book Market 2014: Nonfiction Up, Overall Sales Down*. https://publishingperspectives.com/2015/06/german-book-market-2014-nonfiction-up-overall-sales-down/

IBM. 2021. *What is facilities management?* https://www.ibm.com/topics/facilities-management

IBM. n.d. *650 RAMAC announcement*. https://www.ibm.com/ibm/history/exhibits/650/650_pr2.html

International Federation of Robotics (IFR). 2020a. *Executive Summary World Robotics 2020 Industrial Robots*. https://ifr.org/img/worldrobotics/Executive_Summary_WR_2020_Industrial_Robots_1.pdf

IFR. 2020b. *IFR Press Conference*. https://ifr.org/downloads/press2018/Presentation_WR_2020.pdf

IFR. 2020c. *Executive Summary World Robotics 2020 Service Robots*. https://ifr.org/img/worldrobotics/Executive_Summary_WR_2020_Service_Robots.pdf

International Labour Organization (ILO). 2019. Assessing the Effects of Trade on Employment: an Assessment Toolkit. International Labor Organization Office, Geneva, Switzerland.

ILO. 2020. The future of the work in the digital economy. http://www.ilo.org/wcmsp5/groups/public/---dgreports/---cabinet/documents/publication/wcms_771117.pdf.

ILO. 2020. *ILO Monitor: COVID-19 and the world of work – Sixth Edition*. Geneva, Switzerland: International Labour Organization.

ILO. 2020b. *A Global Survey of Enterprises: Managing the Business Disruptions of COVID-19.* Geneva, Switzerland:
International Labour Organization. https://www.ilo.org/actemp/publications/WCMS_760306/lang--en/index.htm.

International Monetary Fund (IMF). *Exchange Rates incl. Effective Exchange Rates.* https://www.imf.org/external/np/fin/data/param_rms_mth.aspx

IMF, Organisation for Economic Co-operation and Development (OECD). 2020. *The recording of crypto assets*. 14th Meeting of the Advisory Expert Group on National Accounts, Virtual Meeting. https://unstats.un.org/unsd/nationalaccount/aeg/2020/M14_5_4_Crypto_Assets.pdf

IMF. 2018. *Measuring the Digital Economy.* Washington, D.C.

International Telecommunications Union (ITU). 2020. *Economic Impact of COVID-19 on Digital Infrastructure: Report of an Economic Experts Roundtable organized by ITU*. GSR-20 Discussion Paper. Geneva, Switzerland: International Telecommunications Union. https://www.itu.int/en/ITU-D/Conferences/GSR/2020/Documents/GSR-20_Impact-COVID-19-on-digital-economy_DiscussionPaper.pdf

Inter-Secretariat of Working Group on National Accounts (ISWGNA). 2020. Recording and measuring data in the System of National Accounts. *14th Meeting of the Advisory Expert Group on National Accounts.*

ITU. 2021. *Internet users by region and country, 2010-2016*. https://www.itu.int/en/ITU-D/Statistics/Pages/stat/Treemap.aspx

J. Alvarez, et al. 2021. Forging Economic Resilience in the People's Republic of China Through Value Chain Upgrading and Economic Rebalancing. *ADB Briefs Series No. 178*. doi: 10.22617/BRF210172-2.

J. Defourny and E. Thorbecke. 1984. " Structural Path Analysis and Multiplier Decomposition within a Social Accounting Framework." The Economic Journal 94 (373): 111-136.

J. Mitchell. 2018. *A Proposed framework for Digital Supply-Use Tables*. OECD. https://www.oecd.org/officialdocuments/publicdisplaydocumentpdf/?cote=SDD/CSSP/WPNA(2018)3&docLanguage=En

J. Mitchell. 2020. *Guidelines for Supply-Use tables for the Digital Economy.* OECD Informal Advisory Group on Measuring GDP in a Digitalised Economy.

J. Round. 2003. "Social Accounting Matrices and SAM-based Multiplier Analysis." The Impact of Economic Policies on Poverty and Income Distribution: Evaluation Techniques and Tools 261 (276).

J. Shalf. 2020. *The future of computing beyond Moore's Law.* https://doi.org/10.1098/rsta.2019.0061

J. Wertz. 2020. From Malls to Marketplaces: *How The Virtual Shift Is Unfolding For E-Commerce At Scale*. https://www.forbes.com/sites/jiawertz/2020/10/15/from-malls-to-marketplaces-how-the-virtual-shift-is-unfolding-for-e-commerce-at-scale/?sh=3d064787fa57

K. Barefoot, et al. 2018. *Defining and Measuring the Digital Economy.* United States Department of Commerce, Bureau of Economic Analysis.

K. Lueth. 2018. State of the IoT 2018: Number of IoT devices now at 7B – Market accelerating. https://iot-analytics.com/state-of-the-iot-update-q1-q2-2018-number-of-iot-devices-now-7b/

K. Lueth. 2020. State of the IoT 2020: 12 billion IoT connections, surpassing non-IoT for the first time. https://iot-analytics.com/state-of-the-iot-2020-12-billion-iot-connections-surpassing-non-iot-for-the-first-time/

L. Ioannou. 2020. A brewing U.S.-China tech cold war rattles the semiconductor industry. https://www.cnbc.com/2020/09/18/a-brewing-us-china-tech-cold-war-rattles-the-semiconductor-industry.html. Accessed on 14 May 2021.

L. Nakamura, Samuels, J., & Soloveichik, R. 2016. *Valuing Free Media in GDP: An Experimental Approach.* Retrieved from BEA Working Papers: https://ideas.repec.org/p/bea/wpaper/0133.html

L. Reijnders and G. de Vries. 2018. "Trade, Technology and the Rise of Non-Routine Jobs." *Journal of Development Economics* 135: 412–32.

L. Feinier. 2021. *Biden Signs Executive Order to Address Chip Shortage Through a Review to Strengthen Supply Chains*. CNBC. https://www.cnbc.com/2021/02/24/biden-signs-executive-order-to-address-chip-shortage-through-a-supply-chain-review.html.

LetsBuild. 2021. *How digital technology is changing the construction industry.* https://www.letsbuild.com/blog/how-digital-technology-is-changing-the-construction-industry

M. Agrawal, et al. 2021. COVID-19: *An Inflection Point for Industry 4.0.* McKinsey. https://www.mckinsey.com/business-functions/operations/our-insights/covid-19-an-inflection-point-for-industry-40.

M. Al-Hashimi and A. Hamdan. 2021. *Artificial Intelligence and Coronavirus COVID-19: Applications, Impact and Future Implications*. https://dx.doi.org/10.1007%2F978-3-030-69221-6_64

M. Hilbert and P. López. 2011. *The World's Technological Capacity to Store, Communicate, and Compute Information*. Science, *332*(6025), 60 –65. doi:10.1126/science.1200970

M. Lopez Cobo, et al. 2018. *PREDICT Dataset*, European Commission, 2018, JRC111954.

M. Mühleisen. 2018. The long and short of the digital revolution. *Finance & Development, 55*(002).

M. Mueller and K. Grindal. August 30, 2018. *Is It "Trade?" Data Flows and the Digital Economy*. TPRC 46: The 46th Research Conference on Communication, Information and Internet Policy 2018. Available at SSRN: https://ssrn.com/abstract=3137819.

M. Perry. 2016. *Technology has advanced so rapidly that a laptop computer today is 96% cheaper than a 1994 model and 1,000X better*. AEIdeas. https://www.aei.org/carpe-diem/technology-has-advanced-so-rapidly-that-a-laptop-computer-today-is-96-cheaper-than-a-1994-model-and-1000x-better/

M. Reinsdorf. 2020, October 5. *Status Report on the Work of the Subgroup on the Treatment of Free Products*. Retrieved from UNECE Webinars of the Group of Experts on National Accounts: https://unece.org/statistics/events/webinars-group-experts-national-accounts

M. Timmer, et al. 2012. The World Input-Output Database (WIOD): Contents, Sources and Methods. World Input Output Database. http://www.wiod.org/publications/source_docs/WIOD_sources.pdf.

M. Timmer, Stehrer, R., Los, B., Dietzenbacher, E., & de Vries, G. 2015. An Illustrated User Guide to the World Input–Output Database: the Case of Global Automotive Production. *Review of International Economics, 23*, 575-605.

M. Vollmer. 2018. *What is Industry 5.0?* https://medium.com/@marcellvollmer/what-is-industry-5-0-a363041a6f0a

McKinsey Global Institute. 2016. *Digital Globalization: The New Era of Global Flows*. https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Digital%20globalization%20The%20new%20era%20of%20global%20flows/MGI-Digital-globalization-Full-report.ashx

Michigan State University. 2020. *What is the Difference between CAD, CAE, and CAM?* Retrieved https://online.egr.msu.edu/articles/cad-vs-cae-vs-cam-what-is-the-difference/

N. Ahmad & Ribarsky, J. 2018. Towards a Framework for Measuring the Digital Economy. *16th Conference of the International Association of Official Statisticians (IAOS).* Paris: OECD.

N. Ahmad & Schreyer, P. 2016. Measuring GDP in a Digitalised Economy. *OECD Statistics Working Papers, 7*.

N. Ahmad & van de Ven, P. 2018. *Recording and Measuring Data in the System of National Accounts.* Paris: OECD Publishing.

N. Ahmad Ribarsky, J., & Reinsdorf, M. 2017. *Can potential mismeasurement of the digital economy explain the post-crisis slowdown in GDP and productivity growth?* Retrieved from OECD Statistics Working Papers: https://doi.org/10.1787/18152031

N. Heath. 2020. *What is AI? Everything you need to know about Artificial Intelligence.* https://www.zdnet.com/article/what-is-ai-everything-you-need-to-know-about-artificial-intelligence/

National Research Council. 2006. *Renewing U.S. Telecommunications Research*. Washington, DC: National Academic Press. https://doi.org/10.17226/11711

North American Industry Classification System Association.2018. *NAICS Code Description*. https://www.naics.com/

OECD. 2011. *OECD Science, Technology and Industry Scoreboard 2011*. OECD Publishing, Paris. https://doi.org/10.1787/sti_scoreboard-2011-60-en

OECD. 2014. *Defining the Relevant Market in Telecommunications*. https://www.oecd.org/daf/competition/Defining_Relevant_Market_in_Telecommunications_web.pdf

OECD. 2019. *Measuring the Digital Transformation: A Roadmap for the Future.* OECD Publishing, Paris, https://www.oecd.org/publications/measuring-the-digital-transformation-9789264311992-en.htm

OECD. 2020. *ICT Access and Usage by Households and Individuals*. Retrieved from OECD.Stat: https://stats.oecd.org/Index.aspx?DataSetCode=ICT_HH2

OECD / Inter-American Development Bank. 2016. *Broadband Policies for Latin America and the Caribbean: A Digital Economy Toolkit*, OECD Publishing, Paris, https://doi.org/10.1787/9789264251823-en.

P. Christensson. 2015. *Internet Definition*. https://techterms.com

P. Mullins. 2011. CpSc 100: Introduction to Computing for Liberal Arts. Slippery Rock University. http://cs.sru.edu/~mullins/cpsc100book/IntroToCS.html

Preservation Metadata: Implementation Strategies (PREMIS). 2015. *Data Dictionary for Preservation Metadata version 3.0*. https://www.loc.gov/standards/premis/v3/premis-3-0-final.pdf

R. Bukht and R. Heeks. 2017. *Defining, Conceptualising and Measuring the Digital Economy*. Centre for Development Informatics Global Development Institute, SEED.

R. Bukht and R. Heeks. 2017. Defining, Conceptualising and Measuring the Digital Economy. *Development Informatics Working Paper Series*. Centre for Development Informatics. Manchester, United Kingdom.

R. Consing, et al. 2020. *The Wellness Economy, A Comprehensive System of National Accounts Approach*. Manila: Asian Development Bank.

R. Miller and P. Blair. 2009. *Input-Output Analysis: Foundations and Extensions*. Cambridge: Cambridge University Press.

R. Regan. 2020. *Data Processing*. https://www.encyclopedia.com/science-and-technology/computers-and-electrical-engineering/computers-and-computing/data-processing

R. Shannon. 2012. *Internet File Formats*. https://www.yourhtmlsource.com/starthere/fileformats.html

S. Ahmadi. 2019. *5G NR: Architecture, Technology, Implementation, and Operation of 3GPP New Radio Standards*. https://doi.org/10.1016/C2016-0-04944-6

S. Bryan, et al. 2020. *Creating value in digital farming solutions*. McKinsey & Company. https://www.mckinsey.com/industries/agriculture/our-insights/creating-value-in-digital-farming-solutions

S. Chand. n.d. *Agriculture Development and ICTs in Fiji*. Ministry of Agriculture, Fiji. https://www.itu.int/en/ITU-D/Regional-Presence/AsiaPacific/SiteAssets/Pages/Events/2016/Eagriculture/eagriculture/Session%202_Fiji_Sushma%20Chand.pdf

S. Lund, et al. 2019. Globalization in Transition: The Future of Trade and Value Chains. *McKinsey*. https://www.mckinsey.com/featured-insights/innovation-and-growth/globalization-in-transition-the-future-of-trade-and-value-chains

S. Lund, et al. 2020. What's Next for Remote Work: An Analysis of 2,000 Tasks, 800 Jobs, and Nine Countries. *McKinsey*. https://www.mckinsey.com/featured-insights/future-of-work/whats-next-for-remote-work-an-analysis-of-2000-tasks-800-jobs-and-nine-countries.

S.P. Choudary. 2018. How the Platform Economy Is Reshaping Global Trade. https://knowledge.insead.edu/blog/insead-blog/how-the-platform-economy-is-reshaping-global-trade-9991. Accessed on 14 May 2021.

Statista. 2018. Enterprise artificial intelligence market revenue worldwide 2016-20215. https://blogs-images.forbes.com/louiscolumbus/files/2018/01/AI-for-enterprise-Apps.jpg

Statistics Canada. 2019. *The value of data in Canada: Experimental estimates*. Retrieved April 22, 2021

Statistics Canada. 2021. *Digital supply and use tables, 2017 to 2019*. https://www150.statcan.gc.ca/n1/daily-quotidien/210420/dq210420a-eng.htm

T. Haigh. n.d. *Charles William Bachman*. https://amturing.acm.org/award_winners/bachman_9385610.cfm

Thales. 2021. *5G and IoT in 2021*. https://www.thalesgroup.com/en/markets/digital-identity-and-security/iot/resources/innovation-technology/5G-iot

The Economist. 2015. *The great chain of being sure about things*. https://www.economist.com/briefing/2015/10/31/the-great-chain-of-being-sure-about-things

The Economist. 2019a. *Amazon and Alibaba Are Pacesetters of the Next Supply-Chain Revolution*. https://www.economist.com.

The Economist. 2019b. *Slowbalisation: The steam has gone out of globalization*. https://www.economist.com/leaders/2019/01/24/the-steam-has-gone-out-of-globalisation

The Economist. 2021a. *The digital currencies that matter*. https://www.economist.com/leaders/2021/05/08/the-digital-currencies-that-matter

The Economist. 2021b. *Intel should beware of becoming a national champion*. https://www.economist.com/business/2021/03/31/intel-should-beware-of-becoming-a-national-champion.

T. Simatupang, S. Rustiadi and D. B. M. Situmorang. 2012. *Enhancing the Competitiveness of the Creative Services Sectors in Indonesia* in Tullao, T. S. and H. H. Lim (eds.), Developing ASEAN Economic Community (AEC) into A Global Services Hub, ERIA Research Project Report 2011-1, Jakarta: ERIA, pp.173-270.

Transforma Insights. 2020. *Global IoT market to grow to 24.1 billion devices in 2030, generating $1.5 trillion annual revenue*. https://transformainsights.com/news/iot-market-24-billion-usd15-trillion-revenue-2030

U. Kaufmann and H. Nakagawa. 2015. *Recent developments and changes in demand for tourism in Fiji*. https://www.taylorfrancis.com/chapters/edit/10.4324/9781315773827-24/recent-developments-changes-demand-tourism-fiji-uwe-kaufmann-haruo-nakagawa

United Nations (UN). 2008. *Central Product Classification: Version 2*. New York: United Nations.

UN. 2008*. International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 4*. New York: United Nations. https://unstats.un.org/unsd/publication/seriesm/seriesm_4rev4e.pdf

UN. 2018. *Handbook on Supply and Use Tables and Input Output-Tables with Extensions and Applications*. Department of Economic and Social Affairs Statistics Division, United Nations.

UN, European Commission, IMF, OECD, and World Bank. 2009. *System of National Accounts 2008*. New York: United Nations.

United Nations Conference on Trade and Development (UNCTAD). 2008. *Developing World Now Leads in Production, Export of Information and Communication Goods*. https://unctad.org/press-material/developing-world-now-leads-production-export-information-and-communication-goods

UNCTAD. 2019a. *Structural Transformation, Industry 4.0 and Inequality: Science, Technology and Innovation Policy Challenges*. Geneva, Switzerland: United Nations.

UNCTAD. 2019b. *Digital Economy Report 2019: Value creation and rapture – implications for developing countries*. https://unctad.org/system/files/official-document/der2019_en.pdf.

UNCTAD. 2019c. *Trade war leaves both US and China worse off.* https://unctad.org/news/trade-war-leaves-both-us-and-china-worse

UNCTAD. 2021. *COVID-19 and e-commerce: a global review.* https://unctad.org/webflyer/covid-19-and-e-commerce-global-review

W. Chai and I. Lazar. n.d. *Telecommunications.* https://searchnetworking.techtarget.com/definition/telecommunications-telecom

W. Leontief. 1936. *Quantitative Input and Output Relations in the Economic System of the United States.* Review of Economics and Statistics, 18.

W. Li, C., Nirei, M., and Yamana, K. 2018, November 8. Value of Data: There's No Such Thing as a Free Lunch in the Digital Economy. *Sixth IMF Statistical Forum.* Washington, D.C.: International Monetary Fund.

Wall Street Journal. 2021. *China Creates Its Own Digital Currency, a First for Major Economy.* https://www.wsj.com/articles/china-creates-its-own-digital-currency-a-first-for-major-economy-1161763411

World Development Indicators. 2020. *GDP per capita (current $).* World Bank. https://databank.worldbank.org/source/world-development-indicators

World Economic Forum (WEF). 2019. *Travel and Tourism Competitiveness Report 2019.* http://reports.weforum.org/travel-and-tourism-competitiveness-report-2019/wp-content/blogs.dir/144/mp/files/pages/files/ap3.pdf

WEF. 2020. *The Future of Jobs Report 2020.* Switzerland: World Economic Forum. http://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdf

Wohlers Associates, Inc. 2021. *New Wohlers Report 2021 Finds 7.5% Growth in Additive Manufacturing Industry Despite Pandemic.* http://wohlersassociates.com/press83.html

World Meteorological Organization. 2020. *Valuing Investments In Data Processing and Forecasting Systems.* https://public.wmo.int/en/resources/bulletin/valuing-investments-data-processing-and-forecasting-systems

Z. Bischof, Fontugne, R., and Bustamante, F. 2018. Untangling the world-wide mesh of undersea cables. *Proceedings of the 17th ACM Workshop on Hot Topics in Networks HotNets-XVII.* IIJ Innovation Institute.

Z. Ghanem and L. Huang. 2014. *Value-added exports: measurement framework.* Statistics Canada, Industry Accounts Division.

Z. Wang, et al. 2017. Measures of Participation in Global Value Chains and Global Business Cycles (NBER Working Paper 23222). Cambridge, MA: National Bureau of Economic Research.

Appendix 1. A Standard Input-Output Table

A standard IOT is generally comprised of three quadrants. The first quadrant contains the $\mathbf{Z} = [\mathrm{z}_{ij}]$ matrix, which is a matrix of inter-industry flows of output from industry i (row) to industry j (column). The second quadrant contains the $\mathbf{y} = [y_i]$ vector, which is a column vector of the final consumption of output from industry i. The vector of final demand is comprised of the aggregated final consumption of households, non-profit institutions serving households (NPISH), and government, and gross capital formation. The third quadrant contains the $\mathbf{gva}' = [\mathrm{gva}_j]$ vector, which is a row vector of the gross value-added of industry j.

One of the important features of a standard IOT is its symmetry. Put this simply, in an IOT, total output of industries (i.e., summing columns under intermediate consumption along the rows or $\mathbf{x}'$) is equal to the total output used by industries and by final users (i.e., summing rows along columns or $\mathbf{x}$). Appendix 1 Figure 1 shows the structure of a standard n-industry IOT.

Appendix 1 Figure 1. A standard n-industry input-output table

	Intermediate consumption				Final demand	Gross output
	Industry 1	Industry 2	$\cdots$	Industry n		
Industry 1	Quadrant I: $\mathbf{Z}$				Quadrant II: $\mathbf{y}$	$\mathbf{x}$
Industry 2						
$\vdots$						
Industry n						
Value-added	Quadrant III: $\mathbf{gva}'$					
Gross output	$\mathbf{x}'$					

	Intermediate consumption				Final demand	Gross output
	Industry 1	Industry 2	$\cdots$	Industry n		
Industry 1	z_{11}	z_{12}	$\cdots$	z_{1n}	y_1	x_1
Industry 2	z_{21}	z_{22}	$\cdots$	z_{2n}	y_2	x_2
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$
Industry n	z_{n1}	z_{n2}	$\cdots$	z_{nn}	y_n	x_n
Value-added	gva_1	gva_2	$\cdots$	gva_n		
Gross output	x_1	x_2	$\cdots$	x_n		

The symmetry of the IOT provides an organized visual model of the circular flow resources in any economy. We show below how this can be approached in a similarly organized, but more concise, manner from a mathematical perspective.

Consider an economy with n industries, as the IOT in Appendix 1 Figure 1. Each industry i produces its own output, x_i, where i = 1, 2, ..., n. Each x_i can either be used as inputs to industrial production or finally consumed by households, government, non-profit institutions serving households, and even other industries (the interactions within an IOT are discussed in detail in *Methodological Requirements*). Let z_{ij} represent the monetary value of industry j's purchases of industry i output for intermediate use, and

y_i be the total amount of purchases from industry i intended for final consumption. As is customary in traditional input-output analysis, we will assume that interindustry flows from i to j contemporaneously depend entirely on sector j's total output (Miller and Blair, 2009), which implies that final demand is exogenous. Given these information, in Equation (1), we describe the gross output of each industry i to be broken down across its intermediate users and final users.

$$\mathrm{x}_i = \mathrm{z}_{i1} + \mathrm{z}_{i2} + \cdots + \mathrm{z}_{in} + \mathrm{y}_i, \quad i = 1, 2, \dots., n \tag{1}$$

Given that Equation (1) is a system of n equations, we express it in matrix notation in Equation (2).

$$\begin{pmatrix} \mathrm{x}_1 \\ \mathrm{x}_2 \\ \vdots \\ \mathrm{x}_n \end{pmatrix} = \begin{bmatrix} \mathrm{z}_{11} & \mathrm{z}_{12} & \dots & \mathrm{z}_{1n} \\ \mathrm{z}_{21} & \mathrm{z}_{22} & \dots & \mathrm{z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{z}_{n1} & \mathrm{z}_{n2} & \dots & \mathrm{z}_{nn} \end{bmatrix} \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} + \begin{pmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \\ \vdots \\ \mathrm{y}_n \end{pmatrix}$$

$$\mathbf{x} = \mathbf{Zi} + \mathbf{y} \tag{2}$$

We derive a technical coefficient, a_{ij}, to describe the ratio between the amount of industry i's output used by j and the amount of industry j's output; that is, $\mathrm{a}_{ij} = \mathrm{z}_{ij}/\mathrm{x}_j$. Following the Leontief insight, each a_{ij} is assumed to be unchanging over the course of an accounting period. Stating z_{ij} in terms of a_{ij}, the gross output in Equation (1) becomes

$$\mathrm{x}_i = \mathrm{a}_{i1}\mathrm{x}_1 + \mathrm{a}_{i2}\mathrm{x}_2 + \cdots + \mathrm{a}_{in}\mathrm{x}_\mathrm{n} + \mathrm{y}_i, \quad i = 1, 2, \dots., n$$

which may be re-expressed as

$$\begin{pmatrix} \mathrm{x}_1 \\ \mathrm{x}_2 \\ \vdots \\ \mathrm{x}_n \end{pmatrix} = \begin{bmatrix} \mathrm{z}_{11} & \mathrm{z}_{12} & \dots & \mathrm{z}_{1n} \\ \mathrm{z}_{21} & \mathrm{z}_{22} & \dots & \mathrm{z}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{z}_{n1} & \mathrm{z}_{n2} & \dots & \mathrm{z}_{nn} \end{bmatrix} \begin{bmatrix} \mathrm{x}_1 & 0 & \dots & 0 \\ 0 & \mathrm{x}_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \dots & \mathrm{x}_n \end{bmatrix}^{-1} \begin{pmatrix} \mathrm{x}_1 \\ \mathrm{x}_2 \\ \vdots \\ \mathrm{x}_n \end{pmatrix} + \begin{pmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \\ \vdots \\ \mathrm{y}_n \end{pmatrix}$$

$$= \begin{bmatrix} \mathrm{a}_{11} & \mathrm{a}_{12} & \dots & \mathrm{a}_{1n} \\ \mathrm{a}_{21} & \mathrm{a}_{22} & \dots & \mathrm{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \mathrm{a}_{n1} & \mathrm{a}_{n2} & \dots & \mathrm{a}_{nn} \end{bmatrix} \begin{pmatrix} \mathrm{x}_1 \\ \mathrm{x}_2 \\ \vdots \\ \mathrm{x}_n \end{pmatrix} + \begin{pmatrix} \mathrm{y}_1 \\ \mathrm{y}_2 \\ \vdots \\ \mathrm{y}_n \end{pmatrix}$$

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} \tag{3}$$

Rearranging Equation (3):

$$\mathbf{x} = \mathbf{Ax} + \mathbf{y} \rightarrow \mathbf{x} - \mathbf{Ax} = \mathbf{y} \rightarrow (\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{y}$$

Assuming that $\mathbf{I} - \mathbf{A}$ is nonsingular, we have the fundamental Leontief identity:

$$\mathbf{x} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \tag{4}$$

We refer to $(\mathbf{I} - \mathbf{A})^{-1}$ as the Leontief inverse, which gives the total output requirements from each industry in order to meet final demand for a specific time period. Note that $\mathbf{x}$ from Equation (4) would yield the exact same vector of gross output $\mathbf{x}$ in a standard n-industry IOT. Therefore, we could mathematically represent Appendix 1 Figure 1 through Equation (4).

Appendix 2. Aggregating Matrices

Suppose we have a 4 x 4 input matrix, **Z**:

$$\mathbf{Z} = \begin{bmatrix} z_{11} & z_{12} & z_{13} & z_{14} \\ z_{21} & z_{22} & z_{23} & z_{24} \\ z_{31} & z_{32} & z_{33} & z_{34} \\ z_{41} & z_{42} & z_{43} & z_{44} \end{bmatrix}$$

The dimensions of the aggregator matrix are [n-(q-1)] x n, where n is the original number of industries and q is the number of industries to be aggregated into one sector. Thus, if we were to aggregate two industries, we will need a (4 – 2 +1) x 4 or a 3 x 4 aggregator matrix. To aggregate column vectors, we only need to pre-multiply the aggregator matrix to them[38] while matrices (**Z** in this case) have to be pre- and post-multiplied with the aggregator matrix and its transpose, respectively. Letting **Q** denote the aggregator matrix, these steps are given by the equations:

$$\mathbf{x}_{\mathrm{agg}} = \mathbf{Qx}$$

$$\mathbf{f}_{\mathrm{agg}} = \mathbf{Qf}$$

$$\mathbf{gva}_{\mathrm{agg}} = \mathbf{Qgva}$$

$$\mathbf{Z}_{\mathrm{agg}} = \mathbf{QZQ}^{\mathrm{T}}$$

We now discuss the logic behind aggregator matrices with the aid of some examples. To aggregate industries 1 & 2, we need the following aggregator matrix:

$$\mathbf{Q} = \begin{bmatrix} 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

For industries 1 & 3:

$$\mathbf{Q} = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

For industries 1 & 4:

$$\mathbf{Q} = \begin{bmatrix} 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

For industries 2 & 3:

$$\mathbf{Q} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

And for industries 2 & 4:

$$\mathbf{Q} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

In aggregating industries 1 and 2, we first look at the first row of $\mathbf{Q}$ and ask if we are aggregating the first industry with any other industry. Since we're grouping 1 and 2 together, we input 1 to the entries of the first and second columns. Entries for the third and fourth columns are set to zero since we are not grouping industry 1 with any of the two. We then look at the second column. Since industries 1 and 2 have already been accounted for, we now ask if industry 3 is grouped together with any other industry. Since the answer is no, we only set the entry in the third column (corresponding to industry 3) to 1, with everything else being zero. Lastly, since we've already accounted for the first three industries, we look at the third row of $\mathbf{Q}$ and ask if we are grouping industry 4 with any other industry. Since we are not, we only set the entry in the fourth column to 1, everything else being zero.

In aggregating industries 1 and 3, we first look at the first row of $\mathbf{Q}$ and ask if we are aggregating the first industry with any other industry. Since we're grouping 1 and 3 together, we set the entries in the first and third columns to 1 and input zero to the second and fourth columns. Since industry 2 has not yet been accounted for, we look at the second row and ask if we are grouping it with any other industry. Since the answer is no, we set the entry in the second column to 1, all other entries being zero. Finally, since industries 1, 2, and 3 have already been accounted for, we look at the third row of $\mathbf{Q}$ and ask if we are grouping industry 4 with any other industry. Since we're not, we set the entry in the fourth column to 1 and all others to 0.

Thus, the sequence of industries in an input-output table is crucial when it comes to the use of aggregator matrices. Columns still correspond to the exact order of industries in an input-output table but rows will be adjusted whenever we group industries together. However, inputting values to rows of $\mathbf{Q}$ is still based on the sequence of industries in an input-output table with skips occurring when an industry has already been lumped with another that appeared prior to it.

Appendix Table 1: A comparison of estimation methods for the digital economy

Authors	Definition	Estimation method	Data requirements	Advantages	Limitations
ADB	Digital products generate, process or store digitized data; identified using the CPC 2 and differentiated from analog. The primary producers of such products are the digital industries with their backward and forward linkages defined as digitally enabling and digitally-enabled, respectively.	Input-output analysis framework	National supply-use tables (SUTs) or input-output tables (IOTs) Disaggregation of products and industries in the IOTs by isolating the digital out of the aggregated product and industry groupings.	Produces a finer estimation vis-à-vis other methods and can capture sectoral interdependencies and indirect digital contributions to the economy.	Data availability dependent on the frequency of NSO data releases; assumes fixed technical coefficients within the given data period; national accounts limitations.
Mitchell (OECD)	Digital transactions are either digitally ordered, digitally delivered, or platform enabled. Digital goods and services are aligned with the ICT classification in CPC 2.1. Digital industries are either digitally enabling, digital intermediary platforms, firms dependent on intermediary platforms, e-sellers, or other digital businesses.	Supply-use framework	National SUTs Disaggregation of products and industries in the SUTs by isolating the digital out of the aggregated product and industry groupings.	No need to transform SUTs to IOTs	Data availability dependent on the frequency of NSO data releases; does not fully capture sectoral interdependencies and indirect digital contributions to economy; national accounts limitations.
Barefoot et al. (US BEA)	Digital economy is composed of digital-enabling infrastructure, e-commerce, and digital media; classified using NAICS. Digital-enabling infrastructure include computer hardware, software, telecommunications, IoT, and support services. Digital commodities are identified using six-digit NAICS code.	Supply-use framework	National SUTs Disaggregation of products and industries in the SUTs by isolating the digital out of the aggregated product and industry groupings.	No need to transform SUTs to IOTs	Data availability dependent on the frequency of NSO data releases; does not fully capture sectoral interdependencies and indirect digital contributions to economy; national accounts limitations.
Brynjolfsson et al.	'Free' digital goods and services such as Wikipedia, Facebook, and Google	Extending GDP to GDP-B to capture digital benefits	Survey to measure how much the consumers are willing to pay to give up digital products and services.	Captures economic well-being or welfare and supplements the GDP.	Challenge of conducting a representative survey for various products on a national scale and on a regular basis
Huawei and Oxford Economics	The definition of digital assets is extended to include digital goods depreciable within one year but with the same contribution to production processes as capital, as well as all kinds of capital used by the digital sector including services imported through digital assets abroad.	Total economic returns to accumulated digital investment value including productivity gains and indirect spillover effects	Growth of services from ICT capital stock and contribution of ICT capital stock to GDP growth IOTs to determine shares of digital intermediate inputs considered digital assets	Captures the value generated by the use of digital assets rather than cost of purchasing/ producing them	Intermediate consumption by other industries of digital products that do not have the same characteristics of capital (i.e., are used as components in production processes) are excluded

Notes: ADB ERCD-SDIU = Asian Development Bank, Economic Research and Regional Cooperation Department - Statistics and Data Innovation Unit; OECD = Organisation for Economic Co-operation and Development; US BEA = United States Bureau of Economic Analysis; IMF = International Monetary Fund. Input-output analysis was initially developed by the economist Wassily Leontief.

Appendix Table 2: Main digital industries by International Standard Industrial Classification of All Economic Activities Revision 4

Main Activity Group	Code	Industry
Hardware	2620	Manufacture of computers and peripheral equipment
	2680	Manufacture of magnetic and optical media
Software publishing	5820	Software publishing
Web publishing	6312	Web portals
Telecommunications services	61	Telecommunications services
Specialized and support services	62 6311	Computer programming services, consulting, and other related services Data processing, hosting and related activities

Source: UN. 2008. *International Standard Industrial Classification of All Economic Activities (ISIC), Rev. 4*. New York: United Nations.

Appendix Table 3: ADB Multiregional Input-Output 35-Sector Classification

Code	Sector	Code	Sector
c1	Agriculture, hunting, forestry, and fishing	c19	Sale, maintenance, and repair of motor vehicles and motorcycles; retail sale of fuel
c2	Mining and quarrying	c20	Wholesale trade and commission trade, except of motor vehicles and motorcycles
c3	Food, beverages, and tobacco	c21	Retail trade, except of motor vehicles and motorcycles; repair of household goods
c4	Textiles and textile products	c22	Hotels and restaurants
c5	Leather, leather products and footwear	c23	Inland transport
c6	Wood and products of wood and cork	c24	Water transport
c7	Pulp, paper, paper products, printing, and publishing	c25	Air transport
c8	Coke, refined petroleum, and nuclear fuel	c26	Other supporting and auxiliary transport activities; activities of travel agencies
c9	Chemicals and chemical products	c27	Post and telecommunications
c10	Rubber and plastics	c28	Financial intermediation
c11	Other nonmetallic minerals	c29	Real estate activities
c12	Basic metals and fabricated metal	c30	Renting of M&Eq and other business activities
c13	Machinery, n.e.c.	c31	Public administration and defense; compulsory social security
c14	Electrical and optical equipment	c32	Education
c15	Transport equipment	c33	Health and social work
c16	Manufacturing, n.e.c.; recycling	c34	Other community, social, and personal services
c17	Electricity, gas and water supply	c35	Private households with employed persons
c18	Construction		

Note: M&Eq= Machine and Equipment; n.e.c.= not elsewhere classified
Source: Asian Development Bank