Digital Dependence Index: Methodology

Abstract: This paper serves as a supplement to the Digital Dependent Index. It details the structure of the index and its indicators, clarifies key definitions, the scoring system, and the methodology underpinning the DDI as well as data sources, and explains missing data.[1]

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Definitions

The current debates about digital autonomy and digital sovereignty require a comprehensive, evidence-based, and comparative assessment of how dependent countries are on foreign suppliers. The Digital Dependence Index (DDI) offers an empirical foundation to compare the digital dependencies of leading countries. This index includes the G20 member states and four additional countries (Estonia, Israel, Singapore, and Kenia). With this selection, the DDI focuses on the politically powerful players on the global stage and covers a broad range of countries in terms of geographical location, economic size, and economic and digital development differences.[2] The DDI compares data among these 23 countries to capture the digital

[1] Version from 3. February 2022.

[2] The 23 countries are located in different regions with different levels of GDP per capita and digital capabilities. For instance, according to ICT Development Index 2017 (IDI 2017), Kenya was ranked 138 with the IDI Value of 2.91 (from 0 to 10), and Singapore was ranked 18 with the IDI Value of 8.05, while the GDP per capita in Kenya 2019 was 1817 US$, and that in Singapore 2019 was 65641 US$. See ICT Development Index 2017: https://www.itu.int/net4/ITU-D/idi/2017/index.html#idi2017rank-tab ; World Bank Open Data: https://data.worldbank.org/?name_desc=false

dependencies' complexity, pattern, and nuances.

This DDI captures the complexity of the (inter-)connected digital world. Digital dependence adds to other types of dependence and has produced new layers of global interdependence.[3] In this index, digital dependence is defined in a unit-centric way to indicate "the extent to which actors in a particular country have to rely on foreign-controlled digital technologies to perform digital activities." In this definition, foreign-controlled technologies refer to information, communication, and data technologies (including goods and services) owned by foreign companies or produced and operated in foreign countries.[4] At the same time, digital activities refer to the usage of digital data for all kinds of purposes, including the production of ICT goods. Three aspects play a crucial role here:

- Global digitalization trends involve numerous digital products, infrastructures, and diverse actors. Both the products and the corporations can serve as indicators for digital dependence.[5] Moreover, production networks and value chains are geographically widely distributed. Digital dependence results from a few leading tech giants due to their market dominance, the variegated geographical distribution, and the concentration of supply chains. Due to growing interference and geopolitical dynamics, the stability and security of supply chains cannot be separated from governments' activities and policies.[6]
- To cover a broad range of technologies, the DDI does not distinguish between quality and quantity aspects. Particular digital technologies may be critical to the operation of companies or for the security of countries, whereas quantity refers to the availability of mass consumer ICT products. For example, the reliance on foreign suppliers for the design software, Electronic Design

[3] See e.g. Hills, Jill. "Dependency theory and its relevance today: international institutions in telecommunications and structural power." Review of International Studies 20.2 (1994): 169-186; Strange, Susan. "Finance, information and power." Review of International Studies 16.3 (1990): 259-274; Keohane, Robert O., and Joseph S. Nye Jr. "Power and interdependence in the information age." Foreign Aff. 77 (1998): 81-94.

[4] For the purpose of this index, digital technologies are defined as follows: "ICT products must primarily be intended to fulfill or enable the function of information processing and communication by electronic means, including transmission and display". See UNCTAD, "Implications of Applying the New Definition of 'ICT Goods': UNCTAD Technical Notes on ICT for Development No.1" (UNITED NATIONS, May 2011): 1-2, https://unctad.org/system/files/official-document/tn_unctad_ict4d01_en.pdf and UNCTAD, "International Trade in ICT Services and ICT-Enabled Services Proposed Indicators from the Partnership on Measuring ICT for Development: UNCTAD Technical Notes on ICT for Development No. 3" (UNITED NATIONS, October 2015), https://unctad.org/system/files/official-document/tn_unctad_ict4d03_en.pdf.

[5] Flensburg, Sofie, and Signe Sophus Lai. "Mapping digital communication systems: Infrastructures, markets, and policies as regulatory forces." Media, Culture & Society 42.5 (2020): 692-710.

[6] Drezner, Daniel W., Henry Farrell, and Abraham L. Newman, eds. The Uses and Abuses of Weaponized Interdependence. Brookings Institution Press, 2021.

Automation (EDA), for producing semiconductors could contribute much more to the digital dependence than other application software like most apps provided in Google Play because, without the supply of the EDA, no manufacturer can produce chips, which will cause an economic crisis for various companies, sectors, and countries.[7] On the contrary, even the possible restriction on access to a massive amount of mobile apps in Google Play cannot seriously damage economies in most cases. However, digital dependence on mass consumer products could affect a broad range of actors (countries, companies, or individuals).[8]

- The conditions of digital dependence are closely related to each country's economic structure, industrial development, and growth model. Countries that only consume end products will not depend on the supply of semiconductors. Therefore, the DDI indicator and its underlying definition of digital dependence include a broad spectrum of digital technologies beyond "critical technologies."

Accordingly, the DDI measures the share of foreign suppliers in the total demand for certain digital technologies for each country. As a result of this simple definition, the value of the DDI ranges between 0 and 1. The range of the DDI score can be formulated in the following way:

$$(absolute\ independence)\ 0\ \leq DDI\ \leq 1\ (absolute\ dependence)$$

The closer to 1 the DDI score of a particular state, the greater its digital dependence is. 0 means that a country does not use or consume any foreign-controlled or imported digital technologies, while 1 means that the country does not have any domestic sources of supply for the needed digital technologies. It is worth noting that the relatively lower dependence of one country, defined and measured by the DDI, does not automatically indicate that this country has a competitive ICT sector and, therefore highly independent of other countries.[9]

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[7] The importance of semiconductors for the most high-tech products and the critical role of the EDA in the global semiconductor supply chains are mentioned and discussed in many different reports. For example: see F. P. Analytics, "Semiconductors and the U.S.-China Innovation Race," Foreign Policy, accessed June 29, 2021, https://foreignpolicy.com/2021/02/16/semiconductors-us-china-taiwan-technology-innovation-competition/; Jan-Peter Kleinhans and Nurzat Baisakova, "The Global Semiconductor Value Chain: A Technology Primer for Policy Makers" (Stiftung Neue Verantwortung, October 5, 2020), https://www.stiftung-nv.de/de/publikation/global-semiconductor-value-chain-technology-primer-policy-makers.

[8] For instance, while China is highly vulnerable to the supply of semiconductors, it is probably more vulnerable to the availability of WeChat because the majority of its societal and many commercial activities are highly relying on WeChat for their daily life.

[9] Instead, a country can be very independent of foreign digital technologies simply due to its low demand for them. Hence, the assessment of the digital capability of one country cannot be directly

Conceptual framework and indicators

The DDI is divided into three subindices: Hardware, Software, and Intellectual Property. Each of these subindices comprises multiple indicators, and each of the indicators is divided into several sub-indicators (Table 1).

Digital Dependence Index (DDI)				
Subindex A: Hardware		**Subindex B: Software**		**Subindex C: Intellectual Property**
Indicator I Trade in ICT goods	Indicator II Information-Infrastructure	Indicator III Trade in ICT services	Indicator IV Information Infrastructure	Indicator V ICT-related Patents
•Computers & peripheral equipment •Communication equipment •Consumer electronic equipment •Electronic components •Miscellaneous	•Smartphone •Tablet	•Telecommunications-Services •Computer-Software •IT-Consulting, IT-Design, IT-Management, and IT-Training •Licenses to Computer Software	•Browser •Search Engine •Desktop OS •Mobile OS •Social Media	•Audio-visual technology •Telecommunications •Digital communication •Basic communication processes •Computer technology •IT methods for management •Semiconductors

Table 1. DDI Framework

Trade in ICT goods and ICT services (Subindex A and B)

Concerning the supply chain (i.e., the global division of production), hardware and software industries have different implications for digital dependence. The hardware industry is primarily bound by place. For each step in the supply chain, all factors of production must exist at the same place: factory, skilled workers and engineers, and sometimes also upstream suppliers; a hardware supply chain is sometimes based on

inferred from the DDI score but is left to be further interpreted and analyzed.

an appropriate ecosystem. Therefore, there is less flexibility. To some extent, it is more costly to move the supply chain to another place or to search for a new supply chain.[10] In contrast, the software industry relies on software engineers, whose work and locations do not restrict the cooperation. Accordingly, it is physically easier to find a new supplier for software products.[11] The two subindices include trade indicators in ICT goods and services to capture the different characteristics of dependence resulting from supply chains. Each of these indicators covers a broad spectrum of products in ICT goods and ICT services, as Table 1 shows.

Information infrastructure (Subindex A and B)

As the foundation of the data economy and digital economy ecosystem, software and hardware products have a different impact on digital dependence than supply chains and ICT trade. The second indicator for each subindex, information infrastructure, captures this further dimension of digital dependence. Information infrastructure in the DDI refers to digital technologies that enable the flow of information through different places and between users.[12] Both software and hardware products can serve this function as an enabler of information flow. Digital platforms like browsers, social media, search engines, desktops, and mobile operating systems are selected as sub-indicators that are parts of the subindex of software. Two types of consumer electronics, smartphones and tablets, are taken as sub-indicators grouped into the subindex of hardware. The five selected digital platforms are our online activities' essential parts and enablers. At the same time, the leading firms operating these

[10] For instance, on May 15, 2020, the Taiwanese chipmaker TSMC announced the plan to build new fabs in the US: "Construction is planned to start in 2021 with production targeted to begin in 2024." At least four years are required for building new factories for expanding the global supply chains. This case shows the high cost of building a new supply chain for hardware production. Most ICT goods do not require such high costs for building a new supply chain like semiconductors' production, but the main conditions and challenges remain unchanged. See TSMC, "TSMC Announces Intention to Build and Operate an Advanced Semiconductor Fab in the United States," Taiwan Semiconductor Manufacturing Company Limited, May 15, 2020, https://pr.tsmc.com/english/news/2033.

[11] Zoom´s global expansion during the pandemic showed how fast a software company could build new supply chains, like R&D departments, globally to meet the growth of demand. Aradhana Aravindan Geddie John, "Zoom to Set up R&D Centre and Hire Hundreds of Engineers in Singapore," *Reuters*, December 16, 2020, sec. reboot-live, https://www.reuters.com/article/us-zoom-singapore-idUSKBN28Q0FR; Yuthika Bhargava, "Zoom Opens New Technology Centre in Bengaluru," *The Hindu*, July 21, 2020, sec. Business, https://www.thehindu.com/business/zoom-opens-tech-centre-in-banglore/article32146524.ece.

[12] Our understanding of the information infrastructure bases on the following two definitions: 1. "We define digital platforms as a set of digital resources—including services and content—that enable value-creating interactions between external producers and consumers". 2. "We refer to digital infrastructure as the computing and network resources that allow multiple stakeholders to orchestrate their service and content needs." Accordingly, both digital platforms and digital infrastructure are responsible for enabling the information flow. See Panos Constantinides, Ola Henfridsson, and Geoffrey G. Parker, "Introduction—Platforms and Infrastructures in the Digital Age," *Information Systems Research* 29, no. 2 (June 1, 2018): 381, https://doi.org/10.1287/isre.2018.0794.

digital platforms control most of the data (e.g., Facebook), build comprehensive digital ecosystems (e.g., WeChat), and finally create an overwhelming advantage that other market competitors cannot overcome. In short, the success of these tech giants was built on their quasi-monopoly on "the high-value-added data products."[13] Under this structure, most countries, companies, and consumers are highly reliant on the data products provided by these few tech giants. With this set of sub-indicators, the DDI can add the additional dimension for data dependence that is crucial for the digital economy. In contrast to the data-driven technologies, smartphones and tablets do not take such a dominant role but still have a significant impact on digital dependence because they are necessary devices to access the internet easily. Besides, smartphone producers are better positioned to shape or create their ecosystems.[14] Although the sub-indicators of information infrastructure cover only a few digital products, they are considered critical contributors to digital dependence.

ICT-related intellectual property (Subindex C)

Compared to the subindex of Hardware and Software, the subindex of IP does not directly represent ICT products but rather the innovative capabilities and control over technological pathways that corporations have due to their possession of intellectual property rights. Ultimately, possessing large amounts of patents enables the corporations to increase their competitiveness and market share against other suppliers of ICT products. The subindex of IP includes seven different technology fields (seven sub-indicators): audio-visual technology, telecommunications, digital communication, basic communication processes, computer technology, IT methods for management, and semiconductors. All seven types of patents are related to ICT technologies. The number of patents corporations possess does not necessarily reflect their actual position in the market of related digital technologies because not all patents have the same value and quality.[15] However, the number of patents remains

[13] Steven Weber, "Data, Development, and Growth," *Business and Politics* 19, no. 3 (September 2017): 397, https://doi.org/10.1017/bap.2017.3.

[14] The success of Xiaomi, the Chinese smartphone maker, is a good example of this process. Started with selling smartphones, Xiaomi now successfully built a digital ecosystem by strategically leveraging its smartphone products as a platform. See Haiyang Yang, Jingjing Ma, and Amitava Chattopadhyay, "How Xiaomi Became an Internet-of-Things Powerhouse," *Harvard Business Review*, April 26, 2021, https://hbr.org/2021/04/how-xiaomi-became-an-internet-of-things-powerhouse. The smartphone vendors also decide which online platform company can be the default program, thereby they play a crucial role in determining which company can access the data of a pool of consumers. See Wendy C Y Li, Makoto Nirei, and Kazufumi Yamana, "There's No Such Thing as a Free Lunch in the Digital Economy," RIETI Discussion Paper Series 19-E-022 (Japan: Research Institute of Economy, Trade and Industry, March 2019), 18.

[15] Moreover, researchers also point out that there are still differences in examining patents between national patent offices. Hence, patents granted by different patent offices are not always comparable to each other. see Ruth Knoblich, *Die globale Regulierung geistiger Eigentumsrechte: Interessen,*

a crucial proxy indicator for measuring the market position of certain corporations, which reflects the dependence of countries and companies that do not possess these relevant patents. Corporations in the industry are investing in patent filings to maintain their competitiveness in the market and pay attention to avoid IP infringement.[16] At the same time, leading high-tech giants in the global market are also top patent holders globally.[17] Furthermore, governments view IP policy as a tool for supporting economic interests and technological competitiveness.[18] In short, digital dependence is established and maintained by holding patents.

The DDI framework captures the most critical elements of the ICT sector: ICT trade and supply chains, information infrastructure, software and hardware industry, and Intellectual Property. Comparing the three subindices thus reveals different dynamics of digital dependence.

The scoring system

In line with the definition of the DDI, the scoring for digital dependence indicates the share of foreign suppliers in the total demand of particular countries. All indices receive a score between 0 and 1. Four different index-weightings for the DDI are used, and each weighting reflects the relative importance of a particular aspect (see Table 2). For instance, the scores of the 23 countries included in the DDI range from 0.47 to 0.92 for the period of 2019 in the equally weighted DDI.[19]

There are two steps for calculating the score of the overall DDI for a country in a given year. First, the indicators are multiplied by the appropriate weights within each subindex to which they belong and then aggregated into this subindex. Second, the three subindices are multiplied by the appropriate weights and finally aggregated into the overall digital dependence.[20] The weights within each subindex and the DDI sum up to 1 (i.e., 100%).

Strategien und Einfluss Brasiliens, Indiens und Chinas (VS Verlag für Sozialwissenschaften, 2017), 98, https://doi.org/10.1007/978-3-658-03725-3.

[16] Personal conversations with two Taiwanese scientists from the biotechnology industry in Taiwan and Germany respectively.

[17] "IFI 250: Largest Global Patent Holders," IFI CLAIMS® Patent Services, accessed June 21, 2021, https://www.ificlaims.com/rankings-global-assets-2019.htm.

[18] NSCAI, "2021 the Final Report. The National Security Commission on Artificial Intelligence," 2021, 206, https://www.nscai.gov/2021-final-report/.

[19] The values of digital dependence are rounded to the second decimal place.

[20] There are no particular weightings for the sub-indicators under the indicators of hardware-infrastructure, software-infrastructure, and ICT-IP. The average of these sub-indicators is calculated.

Operationalization of digital dependence: Measuring the share of foreign suppliers of digital technologies in the total demand of a country: DDI value=Subindex A×X + Subindex B×Y + Subindex C×Z.
ICT trade-centric $DDI = Subindex\ A \times 0.45 + Subindex\ B \times 0.45 + Subindex\ C \times 0.1$
Subindex A Indicator Trade in ICT goods (80%) + Indicator Hardware Infrastructure (20%) **Subindex B** Indicator Trade in ICT services (80%) + Indicator Software Infrastructure (20%) **Subindex C** Indicator ICT-IP
Infrastructure-centric $DDI = Subindex\ A \times 0.45 + Subindex\ B \times 0.45 + Subindex\ C \times 0.1$
Subindex A Indicator Trade in ICT goods (20%) + Indicator Hardware Infrastructure (80%) **Subindex B** Indicator Trade in ICT services (20%) + Indicator Software Infrastructure (80%) **Subindex C** Indicator ICT-IP
IP-centric $DDI = Subindex\ A \times 0.1 + Subindex\ B \times 0.1 + Subindex\ C \times 0.8$
Subindex A Indicator Trade in ICT goods (50%) + Indicator Hardware Infrastructure (50%) **Subindex B** Indicator Trade in ICT services (50%) + Indicator Software Infrastructure (50%) **Subindex C** Indicator ICT-IP
Equally weighted DDI $DDI = Subindex\ A \times 0.33 + Subindex\ B \times 0.33 + Subindex\ C \times 0.33$
Subindex A Indicator Trade in ICT goods (50%) + Indicator Hardware Infrastructure (50%) **Subindex B** Indicator Trade in ICT services (50%) + Indicator Software Infrastructure (50%) **Subindex C** Indicator ICT-IP
Hardware dependence $Indicator\ I \times 0.5 + Indicator\ II \times 0.5$
Indicator I (Trade in ICT goods) + Indicator II (Hardware Infrastructure)
Software dependence $Indicator\ III \times 0.5\% + Indicator\ IV \times 0.5$
Indicator III (Trade in ICT services) + Indicator IV (Software Infrastructure)
IP dependence $Indicator\ V$
Indicator V (ICT-IP)

Table 2. Four index-weightings of the DDI

With this scoring system, the digital dependence for each country can be quantified between 0 and 1 (i.e., from 0% to 100%). The DDI score is divided into four levels that enable a simple comparative interpretation. As the degree of digital dependence is equivalent to the degree of the foreign share of digital technologies, 0.5 emerges as a pivotal point. The score of 0.5 represents a symmetrical relationship in which the domestic and foreign suppliers equally cover the total domestic demand. In an interdependent world, symmetric dependence can be seen as an ideal position for a country and serve as a benchmark for evaluating the position of each country.[21] Table 3 differentiates the degrees of digital dependence systematically.

Degrees of Digital Dependence

Degrees	DDI value	Ratio between domestic demand and foreign supply of digital technologies
Absolute independence	DDI = 0	Autarky.
Low sensitivity	0 < DDI ≦ 0.25	Autonomy very high. Domestic digital technology is in a dominant position.
High sensitivity	0.25 < DDI < 0.5	Domestic supply delivers majority of digital tech. Considerable level of resilience.
Low vulnerability	0.5 < DDI ≦ 0.75	Global markets supply majority of digital tech.
High vulnerability	0.75 <DDI < 1	Autonomy very low. Foreign digital technology is in a dominant position.
Absolute dependence	DDI = 1	Foreign digital technologies fully cover domestic demand.

Table 3. Four degrees of digital dependence

The DDI divides digital dependence into three main dimensions: global dependence, bilateral dependence, and platform dependence structure. A distinct structure shapes each layer: interdependence between countries, asymmetrical bilateral dependence on the digital powers, and the dominance of a few platform companies originated from a single country. Each structure captures a different feature of digital dependence: a high degree of stability of interdependence and dependence structure or a shift in a particular country's dependence on one of the three digital powers. Table 4 depicts the three-layers-concept of digital dependence.

[21] We use the concept of sensibility and vulnerability from Nye and Keohane to describe the four levels of digital dependence. This concept is defined as follows: "In terms of the cost of dependence, sensitivity means liability to costly effects imposed from outside before policies are altered to try to change the situation. Vulnerability can be defined as an actor's liability to suffer costs imposed by external events even after policies have been altered." See Joseph S. Nye Jr. and Robert O. Keohane, *Power and Interdependence*, 4th ed. (Boston u.a.: Longman, 2011), 11.

Dimensions of digital dependence	Measurements	Focus
Global dependence structure	1. Overall dependence (DDI value) 2. Hardware dependence 3. Software dependence 4. IP dependence 5. Regional average (DDI value): North America (USA, Canada, Mexico), East Asia (China, Japan, South Korea), and Europe (Germany, UK, France, Estonia, Italy) 6. Autonomy gap	Illustrates the overall dependence structures among all countries in the digital domain. Compares the dependence level of countries with the whole world for the years 2010 and 2019.
Bilateral dependence structure	1. Bilateral dependence on China, the USA, and the EU in trade in ICT goods 2. Dependence on Chinese, US-American, and European platform companies 3. Bilateral dependence on China, the USA, and the EU in ICT-related patents 4. Total ICT-Trade dependence	Shows ICT-trade based bilateral dependence of individual countries on China, the USA, and the EU as the three digital powers. Changing values for bilateral digital dependencies reflect the relative rise and fall of the digital powers as well as the shifting geography of productions networks.
Platform dependence structure	1. Overall dependence on foreign platforms (browser, search engine, social media, desktop and mobile OS, smartphone, and tablet) 2. Market shares of leading platform companies (over 5%) in each country	Highlights the dominance of multinational platform companies in information infrastructure. Users in most countries rely on foreign platform providers.

Table 4. Three dimensions of digital dependence

Methodology for measuring digital dependence based on three distinct datasets

The dataset collected and used in the DDI is derived from publicly available online sources. We use three different types of data to measure digital dependence levels: information infrastructures, trade, and intellectual property. Since all three types of data are based on various data collection methodologies, the measurement method for each dataset needs to be adjusted accordingly. This section briefly introduces each dataset and the measurement method used for it. The differences between the three datasets and the contribution of each dataset to creating the indices and indicators are summarized in Table 5.

Data set on Information Infrastructures (Statcounter-GlobalStats)	**Measures the share of foreign suppliers of digital technologies in domestic markets.**
	Subindex A: hardware dependence Subindex B: software dependence Platform dependence (including dependence on browser, search engine, social media, desktop and mobile OS, smartphone, and tablet) Dependence on American, Chinese, and European platform firms Regional average DDI Value: North America, Europe, and East Asia
Data set ICT Trade (UNCTAD)	**Uses export and import volumes to calculate share of imported ICT goods and ICT services**
	Subindex A: hardware dependence Subindex B: software dependence Bilateral dependence on the US, China, and the EU in Trade in ICT goods Regional average DDI Value: North America, Europe, and East Asia
Data set on Intellectual Property (WIPO)	**Measures foreign patent holders' share of global sum of (nationally) granted ICT patents**
	Subindex C: IP dependence Bilateral Dependence on American, Chinese, and European patent holders Regional average DDI Value: North America, Europe, and East Asia

Table 5. Data sets and sources of DDI

Dataset of information infrastructure

Statcounter-GlobalStats is a web analytics company that provides data about the market share of several digital technologies at the national and global levels. Statcounter-GlobalStats applies a distinct data collection methodology by collecting billions of pageviews of more than 2 million websites globally. It then analyzes the different digital platform providers and device vendors used to view these pages. Using this method, Statcounter provides the data on each selected platform and device vendor's share in each country's total pageviews (the total demand). This feature allows us to identify foreign providers and vendors and calculate their shares within a domestic market representing the levels of digital dependence of a particular country. Based on this dataset, two indicators, information infrastructure under the subindex of hardware and software, are built into the DDI. In addition, we can use this data to create special indicators for measuring the bilateral dependence on American, Chinese, and European platform providers.

The market share of foreign search engines (digital platforms) in China 2018

Search engine	**Country of origin**	**Market share 2018**
Baidu	China	0.69 (69%)
Haosou	China	0.05
Google	US	0.02
Sogou	China	0.05
Shenma	China	0.17
bing	US	0.01
Yahoo!	US	0
Other	Other	0

Market share of foreign search eigines (China 2018) =

Google's market share + bing's market share + Yahoo!'s market share = 0.02 + 0.01 + 0 0 = 0.03

Table 6. Example: measuring the dependence on information infrastructure

Source: Statcounter; https://gs.statcounter.com/

Dataset of Trade in ICT goods and services

The data on exports and imports in the ICT sector, measured by the total value of trade in ICT goods and services, is provided by the UNCTAD (United Nations Conference on Trade and Development). The difference in the dataset between trade in ICT goods and trade in ICT services is that the former collects a country's worldwide total trade and its bilateral trade with other countries. In contrast, the latter only provides a country's worldwide total trade.[22]

The trade data comprises imports and exports data in ICT goods and services, and the imports are equivalent to foreign supplies in a particular country. However, the imports data covers only part of a country's demand for digital technologies. Due to the lack of data for the total domestic demand, the DDI cannot calculate the share of foreign suppliers in that country's domestic market based on the trade data. So instead, we calculate the share of the foreign suppliers in the total trade. The underlying assumption for this approach is that the dependence on the imported ICT goods and services from certain states can be reduced or balanced by exporting ICT goods and services to these states.

Based on this dataset, the DDI incorporates the two indicators, trade in ICT goods and trade in ICT services. Additionally, we can create special indicators to measure the bilateral ICT trade dependence on the US, China, and the EU.

Germany's digital dependence in terms of ICT-trade relations between 2010 and 2019				
Year	**Exports ICT goods (Mio USD)**	**Imports ICT goods (Mio USD)**	**Total trade ICT goods (Mio USD)**	**Foreign share in total trade volume ICT goods**
2010	66 977	101 217	168 194	0.60 (60%)
2011	68 845	100 977	169 822	0.59
2012	63 553	91 072	154 625	0.59
2013	62 871	87 376	150 247	0.58
2014	67 721	94 064	161 785	0.58
2015	61 797	89 254	151 051	0.59
2016	62 964	90 171	153 135	0.59
2017	71 682	102 495	174 177	0.59
2018	77 543	110 557	188 100	0.59
2019	73 181	103 743	176 925	0.59

Foreign share in total trade volume ICT goods (Germany 2010) =

$$\frac{\text{Imports}}{\text{Total Trade}} = \frac{\text{Imports}}{(\text{Imports } + \text{Exports})} = \frac{101217}{(101217\ + 66977)} = 0.6\ (60\%)$$

Table 7. Example: measuring the dependence on trade in ICT goods

[22] It is also worth noting that according to the database of the UNCTAD, the data of trade in ICT services for certain countries in some years are merely estimated.

Source: United Nations Conference on Trade and Development;

https://unctadstat.unctad.org/wds/ReportFolders/reportFolders.aspx?sCS_ChosenLang=en

Dataset of ICT-related Intellectual Property

Patent data is derived from the WIPO IP Statistics Data Center. WIPO collects the number of granted patents by national patent offices categorized by filing office, applicant's origin, and year. According to these categories, the foreign share of patents within a particular jurisdiction could be calculated for each year. This leads, however, to misrepresentations,[23] because this data reflects that countries with a big market and advanced technology sectors like the USA, Japan, the EU, and China attract most foreign patent applications.[24]

The IP dependence subindex captures global dependence structures and globally operating ICT companies.[25] Hence it uses a different method to calculate IP dependence. This subindex calculates the "foreign" share of all granted patents of one year by all national patent offices from a particular country's perspective. In other words, this subindex measures the share of patents not owned by companies from a particular country at the global rather than at the national level. The IP dependence subindex represents the global structure of IP ownership within which individuals, (digital) companies, and states have to operate. This dependence structure both enables and constrains activities. On the one hand, multinational corporations and their home countries actively exploit and leverage intellectual property rights to shape digital technologies' developments and dominate the global markets.[26] On the other hand, when other tech companies wish to join the global markets, they have to rely on patents owned by these leading multinational digital corporations.

[23] Calculating the foreign share of ICT-related patents within a country shows that countries like the USA and Japan are strongly dependent on foreign suppliers. In contrast, other countries which obtain extremely few patent applications, seem highly independent, even when they are neither technologically advanced nor economically more developed than the USA or Japan.

[24] In 2019, 84.7% of the world total patent applications were submitted to national patent offices of the following countries: China, the US, Japan, South Korea, and the European Patent Office. See World Intellectual Property Organization, *World Intellectual Property Indicators 2020.* (Switzerland: WIPO, 2020), 12, https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2020.pdf.

[25] Theoretically, the companies could freely use certain technologies in a country where these technologies are not patented. In reality, it remains questionable whether companies can take advantage of proprietary technologies.

[26] Intellectual property policy and strategic use of it: see NSCAI, "2021 the Final Report. The National Security Commission on Artificial Intelligence," 199–210.

Republic of Korea: Intellectual Property Dependence			
Field of technology	**Country of Origin**	**ICT-related patent grants in 2019**	**Share of foreign ICT patents at the global level in 2019**
1 Audio-visual technology	Republic of Korea	7573	0.85
	Total (all countries)	50907	
2 Telecommunications	Republic of Korea	4653	0.88
	Total (all countries)	37519	
3 Digital communication	Republic of Korea	9612	0.90
	Total (all countries)	96190	
4 Basic communication processes	Republic of Korea	1013	0.91
	Total (all countries)	11296	
5 Computer technology	Republic of Korea	11799	0.91
	Total (all countries)	130256	
6 IT methods for management	Republic of Korea	3211	0.82
	Total (all countries)	18268	
7 Semiconductors	Republic of Korea	9335	0.82
	Total (all countries)	51260	
The average of the foreign share of ICT patents in seven fields of technology for the Republic of Korea			0.87

Share of foreign patents in **Audio-visual technology** at the global level (South Korea 2019) =

$$1-\frac{\text{Total Number of Patents from South Korea}}{\text{Total Number of Patents from all Countries}}=1-\frac{7573}{50907}=1-\ 0.15=0.86$$

Table 8. Example: measuring the dependence on ICT-related patents

Source: WIPO IP Statistics Data Center; https://www3.wipo.int/ipstats/index.htm?tab=patent&lang=en

Appendix A: shortage and limitation of the data sets used in the DDI

Missing data in information infrastructure

There is no missing data in this dataset. However, the data on social media in China does not reflect the reality. For example, according to Statcounter, Facebook had a market share of 51.07% in China in 2017; and Twitter had a market share of 28.2% in China in 2019. But due to the Chinese internet policy, the major foreign social media, including Facebook and Twitter, were forbidden to operate in China since 2009.[27] Also, considering that Chinese social media hold a dominant position in Chinese society, there is no evidence to speak of a Chinese dependence on foreign social media companies. Therefore, it is justified to adjust China's dependence on foreign social media to zero

Shortage and limitation of the dataset of trade in ICT goods and services

Concerning trade in ICT goods, two issues should be discussed. First, the trade data of China, Hong Kong, and Macao are separately recorded. This means, when we add up the total trade of China, Hong Kong, and Macao, the intra-China trade between the three places is also included, but the intra-China trade is irrelevant to China's trade relations with the world. Hence, in the calculation of the DDI, this part of the trade data is excluded from China's total trade with the world.

The second issue is the case of Singapore, which is also included in the DDI. Unlike most countries in our dataset, Singapore serves mainly as a place for transit trade. As a result, Singapore imports and exports more ICT goods than the domestic demand and local production capacity. This special status could affect the level of Singapore's digital dependence, but we see no productive way to exclude this effect. However, we would also like to point out that this effect can be seen as part of the geographical influence on digital dependence, just like the impact of globally distributed supply chains.

Missing data in trade in ICT goods and services

This dataset is incomplete. There are two types of missing data. The first type is that when values of trade data for a country are missing in some years but available in most other years. The DDI calculates the average of these countries' available values and

[27] For example: see Rocky, "2020 被中国封锁的网站、软件、应用程序 Apps 列表 (2020 List of websites, software, applications Apps blocked in China)," *Ganbey* (blog), January 18, 2021, https://www.ganbey.com/blocked-website-apps-in-china-1468.

replaces the missing data with this average. For example, the value of Canadian ICT services trade data in 2019 is missing, so we calculate the average of Canadian ICT services trade values from 2005 to 2018 and replace the missing data for 2019 with the result of 0.35.

The second type refers to a country whose values are entirely missing. In this case, this country's missing data is replaced with the average value of all other countries between 2010 and 2019 (survey year). Saudi Arabia and South Africa are the only two countries whose data for trade in ICT services are entirely missing from 2005 to 2019.

ICT-related patent grants as a proxy for digital dependence

The dataset shows the granted patents. Different from the data on ICT trade and information infrastructures, patent data does not automatically reflect actual transactions among companies or users. From the vantage point of a company, it might not pose a problem if its home country is highly dependent on foreign ICT patents according to the index value, as long as the firms do not want to produce or trade digital products or services protected by patents. However, patents as a proxy are very informative on the national economy level. The global patent dependence structure illustrates the macro-economic position of a national economy and refers thus to the "costs" for digital activities. Consequently, a distinct gap between the value of the subindex and the firm-level experience of digital dependence emerges. How to reconcile these perspectives for particular countries needs to be further analyzed.

Missing data in ICT-related patents

Where patent numbers are missing, annual data points are defined as zero value. We assume that rather than missing data, zero is the more likely value for these cases.[28]
The reasons for this are the following: first, our data collection and analysis show that the cases of no values are only found in countries whose total amounts of patents are extremely low. On the other hand, countries with a more significant share in the total patents of the world do not have any missing value.
Secondly, the missing values occur systematically in certain technological fields or in certain periods where the companies from a certain country are generally neither active nor competitive. For instance, from 2000 to 2019, Argentina is missing 13 out of 20 values in IT management methods. In addition, the average patent granted in the same field in the other seven years is only 1.25. It means that companies from Argentina were granted only nine patents worldwide in those seven years. We can

[28] See WIPO, "About the WIPO IP Statistics Data Center," accessed June 25, 2021, https://www.wipo.int/ipstats/en/help/index.html.

assume with some confidence that the missing value is zero, as it reflects the average capacity of Argentine companies.

Appendix B: mean imputation for missing data

Indicator: trade in ICT services

Indicator	Country	Year of missing value	Calculation of the mean	The mean for missing value
ICT-Services	France	2005-2010	Average calculated on France's scores of dependence in trade in ICT services between 2011 and 2019	0,51
ICT-Services	Singapore	2005-2010	Average calculated on Singapore's scores of dependence in trade in ICT services between 2011 and 2019	0,54
ICT-Services	Estonia	2012	Average calculated on Estonia's scores of dependence in trade in ICT services between 2005 and 2011, and 2013 and 2019	0,41
ICT-Services	Canada	2019	Average calculated on Canada's scores of dependence in trade in ICT services between 2005 and 2018	0,35
ICT-Services	Israel	2019	Average calculated on Israel's scores of dependence in trade in ICT services between 2005 and 2018	0,10
ICT-Services	Mexico	2019	Average calculated on Mexico's scores of dependence in trade in ICT services between 2005 and 2018	0,43
ICT-Services	Kenya	2018 and 2019	Average calculated on Kenya's scores of dependence in trade in ICT services between 2005 and 2017	0,19
ICT-Services	Saudi Arabia	2005-2019	Average calculated on the scores of dependence of all 21 countries (except Saudi Arabia and South Africa) in trade in ICT services between 2005 and 2019	0,45
ICT-Services	South Africa	2005-2019	Average calculated on the scores of dependence of all 21 countries (except	0,45

			Saudi Arabia and South Africa) in trade in ICT services between 2005 and 2019	

Indicator: trade in ICT goods

Indicator	Country	Year of missing value	Calculation of the mean	The mean for missing value
ICT-Goods	Kenya	2011, 2012, 2014	Average calculated on Kenya's scores of dependence in trade in ICT goods between 2005 and 2010, 2013, and 2015 to 2019	0,96

Indicator Intellectual Property 2000-2019 by 7 different technological fields (total: 140 values)

Indicator	Country	Total possible values	Total amount of missing values	Substitute for missing value
Patents / Intellectual Property	Argentina	140	81	No
Patents / Intellectual Property	Brazil	140	27	No
Patents / Intellectual Property	Estonia	140	76	No
Patents / Intellectual Property	Indonesia	140	118	No
Patents / Intellectual Property	Kenya	140	131	No
Patents / Intellectual Property	Mexico	140	46	No
Patents / Intellectual Property	Saudi Arabia	140	66	No
Patents / Intellectual Property	Singapore	140	1	No
Patents / Intellectual Property	South Africa	140	3	No
Patents / Intellectual Property	Turkey	140	46	No