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The Uneven Geography of Digital Infrastructure: Does It Matter?

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The Uneven Geography of Digital Infrastructure: Does It Matter?

Ioannis Papadakis[1] and Maria Savona[2]

Abstract

With data becoming an essential production input, we look at the location of data and cloud centres (DCCs) and explore drivers and potential implications of the uneven geography of this increasingly strategic digital infrastructure. We show that DCCs are located in a few, top digital services exporter countries, whereas their highest intensity is in small countries specialised in financial services exports. We argue that the uneven location of DCCs can lead to a "digital global core-periphery" structure. We conjecture a "Data Haven Hypothesis", where DCCs are especially present in tax havens, or in countries where top digital exporters can offshore energy-intensive digital infrastructures. We conclude by suggesting a research agenda on DCCs.

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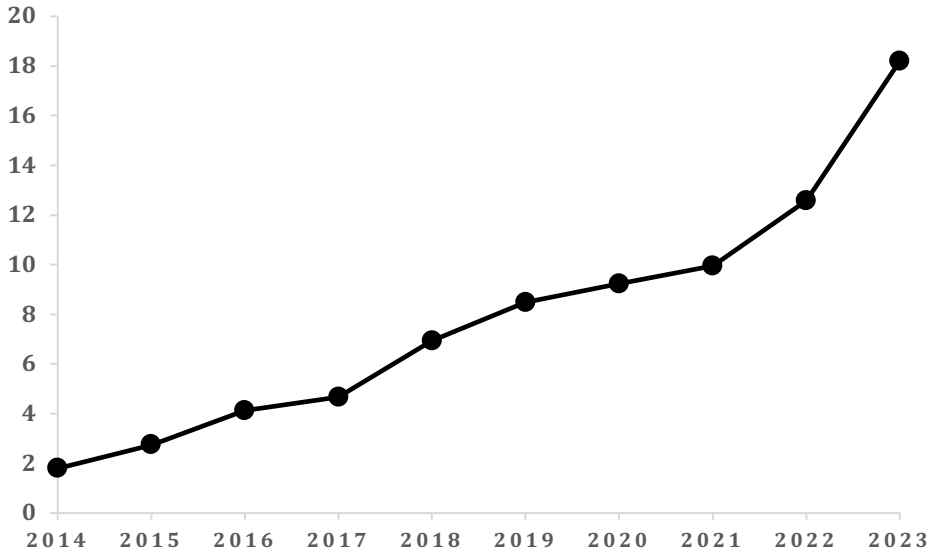
1. Introduction

Data centres and cloud service providers have become essential digital physical infrastructure, alongside optic fibres, submarine cables and others. They are the tangible component of investments in emerging digital technologies such as data acquisition, data management, software, artificial intelligence, which are intangible in nature (Savona et al., 2022; Corrado et al., 2023).

As firms increasingly invest in emerging digital technologies, they need to scale up their capacity to process large data in a cost-effective and reliable manner. According to IMF et al. (2023), *"Cloud computing services, defined as "computing, data storage, software, and related IT services accessed remotely over a network, supplied on demand and with measured resource usage that allows charging on a pay-per-use basis", are increasingly used to replace ownership of on-premises IT equipment."* In fact, there has been a large increase in private spending for the construction of data centres in the US. We can see in **Figure 1** that it increased from 1.8 billion dollars in 2014 to 18.2 billion dollars in 2023. Therefore, there is also an ongoing trend of ***outsourcing and offshoring*** of data-intensive activities and services ***to external cloud service providers and data centres.***

Figure 1: US private construction value of Data Centres, in billions of US$



Data source: US Census data - Construction Spending

This paper focuses on the geographical distribution of data centres and cloud service providers. First, it looks at trends in digital service trade to consider whether the concentration of digital infrastructure in certain countries is simply linked to their specialisation in digital service trade. We find that, not unexpectedly, a high *share* of DCCs is located in the US, Germany, and the

UK, which are also fairly large top digital services exporting countries. However, interestingly, the *intensity* of data and cloud centres is higher in a few smaller countries which specialise in financial services exports and are known to be tax havens (The Tax Justice Network, 2023). We therefore offer additional explanations of the uneven geography of data centres and discuss potential drivers and implications in the context of what we spell out as a 'data haven hypothesis'.

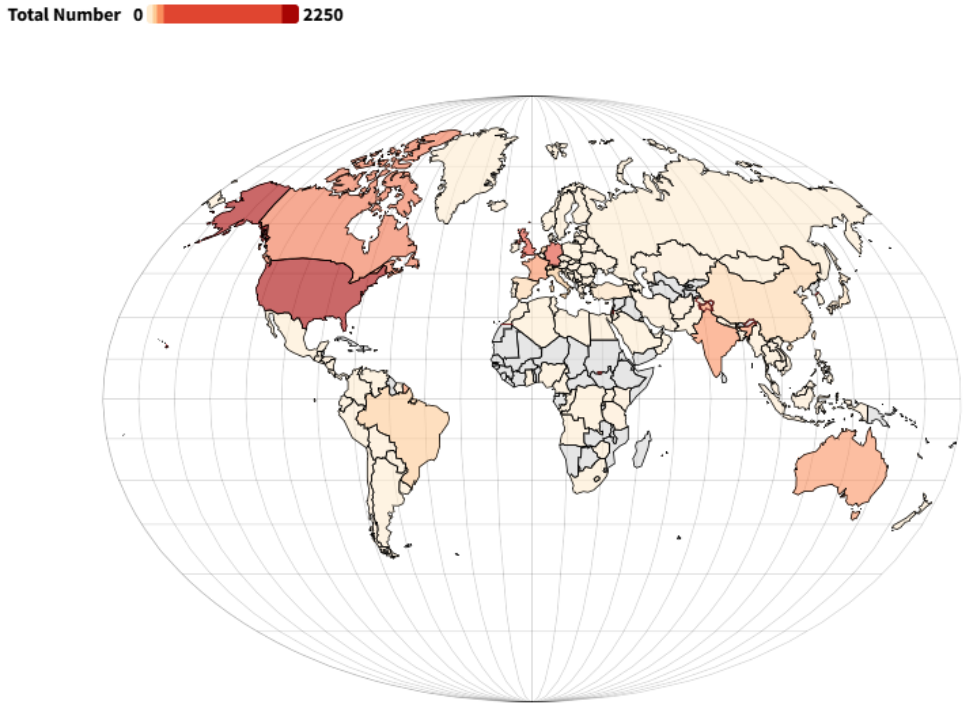
The paper is organised as follows: we first show evidence of the concentration of data centres and cloud services (Section 2.1); we then turn to the reasons why it matters and look at the trends in different digital services exports across high and low/middle income countries that might be associated with the location of data centres (Section 2.2). Next, we explore additional determinants of the geography of digital infrastructure, linked to regulatory arbitrage around taxes, data protection and environmental regulation (Section 3.1), and environmental conditions (Section 3.2). We discuss the presence of a `data haven hypothesis' that links the above to the geopolitical relationships around digital infrastructures (Section 4). Last, we discuss policy implications with the main aim of harnessing the potential of hosting digital infrastructure while mitigating the potential side-effects of its uneven geography (Section 5).

2. The empirical evidence

2.1. The geography of digital infrastructure

In **Figure 2** we map the number of data and cloud centres, highlighting with a dark red colour countries that have a higher number. The geography of data and cloud centres is uneven, as there is large heterogeneity across counties**.**

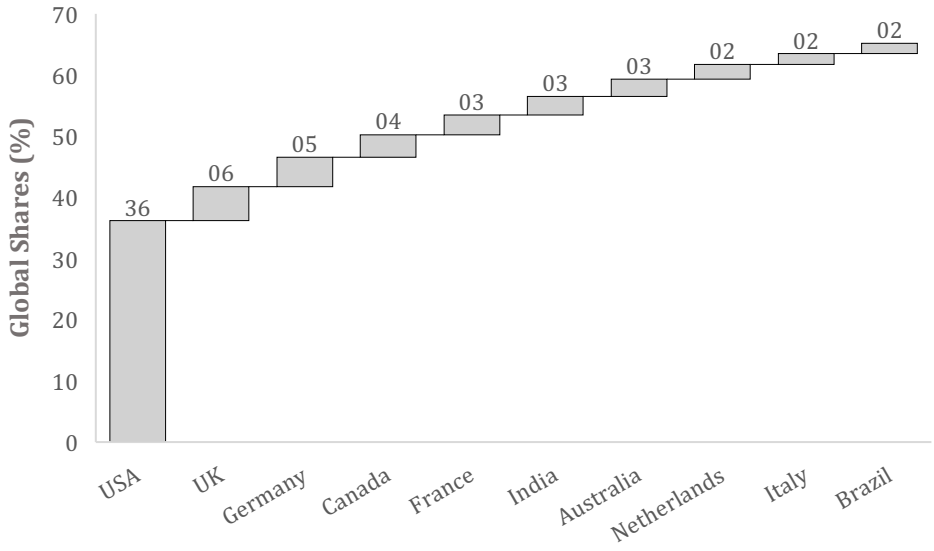
Figure 2: Total Number of Data Centres and Cloud Service Providers



Notes: This figure maps the total number of data centres and cloud service providers. Dark orange countries have a higher number of data centres and cloud service providers. In colour gray are countries without available data.
Source: data on data centres and cloud infrastructures from www.datacentermap.com

To understand this in more detail, ***Figure 3 identifies the top countries in terms of shares of global data centres and cloud service providers. Germany, the UK, and the US are the top 3*** out of the 134 countries covered in the data. This finding is consistent with the view that data centres are associated with trade as the top 3 countries are among the top exporters of (digital) services worldwide (UNCTAD, 2023). There is also a large concentration. The US alone accounts for one in three data and cloud centres worldwide. The countries in the top 10 list are also all large and advanced, except for India and Brazil, which are large emerging countries, and the Netherlands, which is not a large country.

Figure 3: Data Centres and Cloud Service Providers – Shares



Source: data on data centres and cloud service providers are sourced from www.datacentermap.com. This is a live database accessed in February 2024. The data is thus not historical and does not provide information on the year a data centre or cloud service provider was established nor on their size.

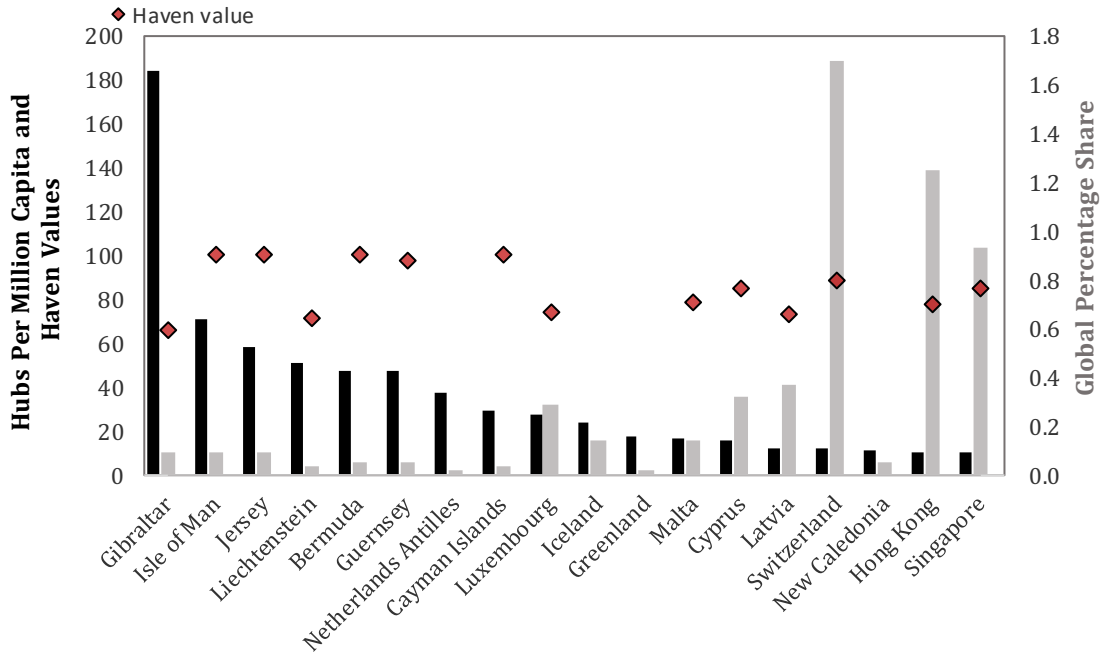
A very different picture emerges when considering the size differences across countries. **Figure 4 considers the intensity** of this digital infrastructure. It shows the number of data centres and cloud infrastructure per million people. When it is standardized by the 2022 population, the intensity of digital infrastructure is substantially higher in a particular subset of small countries, that is, those that are considered tax havens (i.e. they have a Haven Score which is close to 100).[3]

Interestingly, the countries in **Figure 4** are all small, relatively advanced countries, with some of them (Switzerland, Hong Kong and Singapore) also displaying a relatively higher share of global data centres, albeit not being included in the top ten countries in **Figure 3**. Germany, the UK, and the US do not appear in **Figure 4**, as they have only 4, 5, and 7 data centres and cloud infrastructures per million people, respectively.[4]

[3] The Tax Justice Network assigns a Haven Score (HS) which "is a measure of how much scope for corporate tax abuse the jurisdiction's tax and financial systems allow." The HS takes values from 0 to 100. The countries that rank at the top (≥85 HS) according to the HS are British Virgin Islands, Cayman Islands, Bermuda, Switzerland, Jersey, Singapore, United Arab Emirates, Bahamas, Cyprus, Guernsey, Isle of Man, Turks and Caicos Islands, and Anguilla. Eight out these thirteen countries are in **Figure 4**.

[4] This picture does not change if we measure intensity using GDP values in the denominator – see **Figure A1** in the Appendix.[4] Isle of Man, Bermuda, Latvia, Cayman Islands, Iceland, Greenland, Malta, and New Caledonia appear in both figures: what we capture is not driven just by the low population density nor by cross-country differences in the population.

Figure 4: Data Centres and Cloud Service Providers – Intensity



Source: data on data centres and cloud service providers are sourced from www.datacentermap.com. Haven values (left-hand y-axis) are sourced from the Tax Justice Network and take values between 0 and 100 and they are not available for Netherlands Antilles, Iceland, Greenland, New Caledonia.

Our takeaway is therefore that the geography of digital infrastructure turns out to be very uneven in both shares and intensity of data centres and cloud providers, although the countries with highest shares are not those that show high intensity, which leads us to believe that the location of data centres might be associated with different drivers.

Before turning to the broader implications, we need to understand how their location matters and what the location's drivers are. Given that trade relates to digital infrastructure, we turn to digital service trade in the next section to explore this relationship and discuss the role of data- and cloud centres-intensive countries.

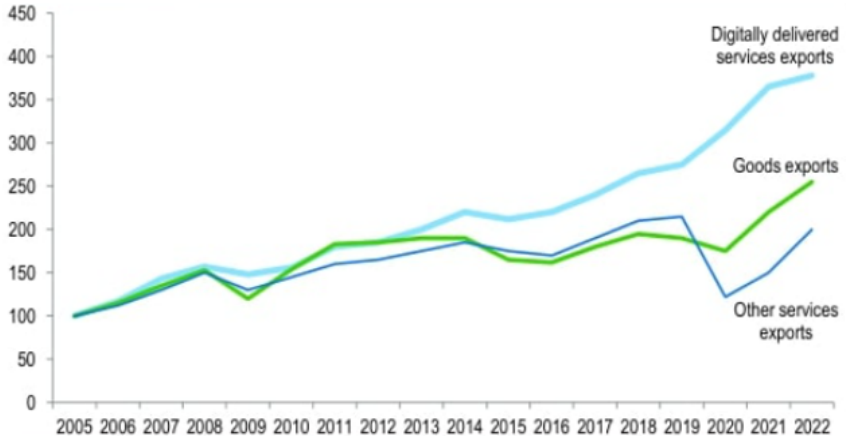
2.2. Digital services trade

Trade increasingly depends on the presence of digital infrastructure, such as data and cloud centres, as it becomes more digitised. Freund and Weinhold (2002) find that the number of internet hosts (internet penetration) in a country has a strong positive association with international trade in services. Indeed, the share of services in total world exports has increased significantly over the last forty years: it peaked at 25% in 2019, up from 19% in 1982, and stood at

23%[5] in 2022. Yet, and as shown in **Figure 5**, this increase is due to the rise of digitally delivered services.[6] This is consistent with **Figure 3,** where top digital exporters account for the largest shares of digital infrastructures. At the same time, however, we show in **Figure 4** that the intensity is higher in countries that are considered tax havens.

Taken together, this evidence suggests that there might be different driving forces of the location of data and cloud centres.

Figure 5: Growth of goods, services and digitally delivered services exports



Source: WTO and Standard Chartered Research. Link: tradefinanceglobal.com

To understand how fast this is changing over time for different types of services, we unpack the different components[7] that make up the digitally delivered services exports (light blue line in **Figure 5**) in **Figure 6**. This breakdown exercise shows that **Figure 5** hides a large degree of heterogeneity, for instance in terms of growth across developed and developing countries, and, within them, in DCCs' intensive countries.[8]

[5] https://ourworldindata.org/trade-and-globalization

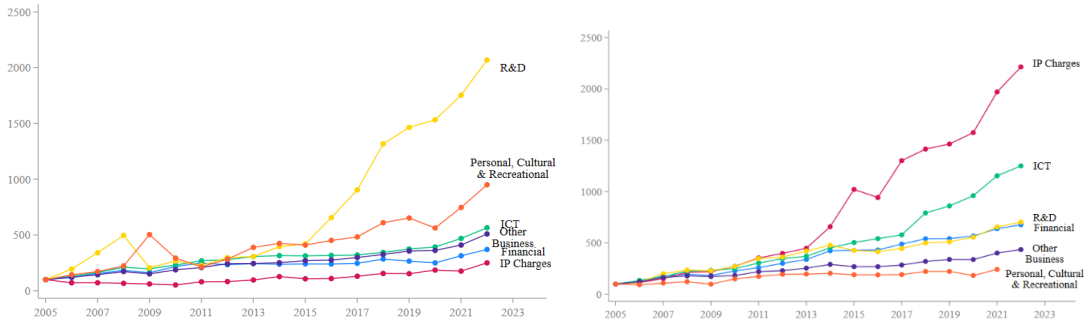
[6] According to **Figure 5**, digitally delivered services exports grew faster than other service exports. Hence, their share in total services exports has increased.

[7] See Table 4.1 here for a more detailed breakdown of digitally delivered services, according to the WTO definition.

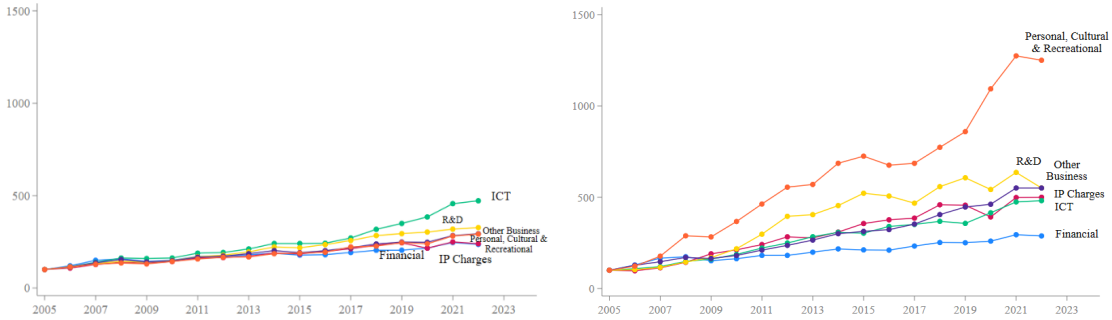
[8] We refer to the standard UNCTAD classification of developed and developing countries. A developing economy whose GDP per capita averaged over US$5,907 from 2019 to 2021 is high income, and one between this income threshold and US$1,313 is middle income. The rest are low-income developing countries.

Figure 6: Change of Exports of Digitally Delivered Services, base year 2005=100

Panel A: Developing countries, low (left) and middle (right) income



Panel B: Developed countries (left), DCCs' intensive countries (right)



Source: data from UNCTAD, own calculations. Notes: All the lines represent different types of digitally delivered services according to the WTO definition.[9] Financial services comprise insurance, pension, and financial services; IP Charges services comprise charges for the intellectual property, not included elsewhere; ICT services comprise telecommunications, computer and information services; R&D services comprise research and development services; Other Business services comprise professional, management consulting, architectural, engineering, scientific, other technical, trade-related, and other business services not included elsewhere; Personal, Cultural & Recreational services comprise audio-visual and related services, health, education, heritage, and recreational services. Panel B's right figure includes the following countries - Bermuda, Cayman Islands, Switzerland, Liechtenstein, Netherlands Antilles, Luxembourg, Malta, Cyprus, Latvia, New Caledonia, Singapore, Iceland, China, Hong Kong SAR.

While having lower shares in digital service exports, developing countries – and particularly middle income countries - seem to have outpaced developed countries in terms of the growth of digital service exports.[10]

DCCs' intensive countries digital service growth in export performance is dominated by cultural and recreational services, R&D and other business services, according to **Figure 6**. Middle income countries exibit a very rapid increase in export of IP charges.[11]

[9] See Table 4.1 here for a more detailed breakdown of digitally delivered services, according to the WTO definition.
[10] It should be noted that this is not to be confused with absolute changes. The larger growth rates we find for Developing countries are largely due to the low levels of digital services trade at the beginning of the period in these countries.

In relation to the evidence on location of DCCs presented above, it is worth discussing the trends of IP charges within digital service exports. Exports of IP charges are often the result of FDI and IP transfers. Their substantial growth in middle income countries over the past two decades (right figure in Figure 6, Panel A) might be associated with return flows of royalty payments and licence fees from middle income countries that are recipients of high income countries' FDIs. In other words, the royalties generated by IP and patents owned by firms in high income countries – or indeed in their affiliates in middle income countries - are reflected in middle income countries' IP digital exports. However, this trend may not only be the result of developed countries' strong position as exporters of capital and their high patent intensity, but also of their strategy of shifting IP related financial gains to other countries. DCCs' intensive countries are a very small subset of middle and high income countries, and they show a high increase of IP charges export over the period considered, albeit less important than other digital service exports (e.g. personal and recreational services). We will unpack these conjectures below.

3. Determinants of DCCs' location

3.1. Regulatory arbitrage

Differences in regulatory regimes might drive the location of data centres. For instance, data privacy regulations that mandate the privacy of high-income individuals or businesses, including the EU data protection (see e.g. Ferracane et al., 2023; Bacchus et al., 2024) that ensures high data standards, can make digital infrastructure more secure for storing sensitive information. Another instance is the arbitrage on environmental or tax regulation stringency.

Many of the countries that are highly intensive in data centres are also considered tax havens, as shown above. Therefore, their high digital infrastructure intensity might be the result of their specialisation in either banking and financial services, or IP charges-related services, which we have shown is the highest growing component of digital trade in middle-income developing countries, albeit not specifically the DCCs' intensive countries (**Figure 6**). Therefore, a high intensity might mean that these digital services may be prone to tax avoidance and therefore the result of tax regimes that attract IP revenue shifts (Haufler and Schindler, 2023; Alstadsæter

[11] When Intellectual Property (IP) is used in a foreign country, the users pay IP charges to the IP owners. IP Charges are defined (UN et al., 2011) as "Charges for the use of proprietary rights, such as patents, trademarks, copyrights, industrial processes and designs, trade secrets and franchises, where rights arise from research and development, as well as from marketing. Charges for licenses to reproduce and/or distribute intellectual property embodied in produced originals or prototypes, such as copyrights on books and manuscripts, computer software, cinematographic works and sound recordings, and related rights, such as for the recording of live performances and for television, cable or satellite broadcast."

et al., 2018).

Empirically, the relationship between tax havens and digital services (such as IP) has been explored in Hebous and Johannesen (2021) for Germany and Accoto et al. (2023) for Italy. They have emphasised the role that multinational firms play in strategically shifting profits offshore, and it has been generalised and corroborated in more aggregate data and for a larger set of countries in Santacreu (2023). Haufler and Schindler (2023) show that low corporate tax regimes, and particularly patent boxes,[12] may result in (IP-related) profit shifting rather than increased incentives for innovation.

We have shown that tax havens are over-represented in the list of data centres-intensive countries. With the data available, we cannot show a specific link between profit shifting in tax havens and the intensity of DCCs, but we consider this phenomenon worthy of further scrutiny. *Data has become a critical production input and a major source of income. If it is being stored in offshore data centres, we may see a rise of data havens*, with potentially detrimental effects for the environment and the tax base of countries. We discuss the implications in Section 4.

3.2. Environmental conditions

The cost of building digital infrastructure is not negligible and varies across countries. According to a US Chamber of Commerce report, "On average, it costs $60.9 million to build a data centre in Brazil, compared with $51.2 million in Chile and $43 million in the U.S." (USCC and HW, 2014). Cost differences are reflected in where data centres are located and depend on local environmental conditions. A colder climate, the availability of energy and skilled employees at relatively low costs, the absence of natural disasters and the short distance to producers or consumers of digital products are factors that lower the operational and transaction costs (for instance, they make the broadband speed faster and more reliable). These factors can help a location attract digital infrastructure.

Some countries may face lower costs than others, due to their location. For instance, digital infrastructure relies heavily on natural resources, particularly water, and environmental conditions. Over the past year, Google's hyper-scale data centres have used an average of 2.1 million litres of water a day to cool their servers (Zhang, 2024). Therefore, access to cheap energy and the ability to keep the digital infrastructure cool using water-based solutions are expected to play an increasingly important role as drivers of the location of digital infrastructure. Indeed, the extensive reliance of data centres' cooling systems on water can be concerning.

[12] Patent boxes are used to incentivise businesses to invest in R&D by taxing patent revenues at lower tax rates than other business revenues.

Environmental protection might be at risk, given the evidence that by 2050 more than half of the global population will live in water-stressed areas (Schlosser et al., 2014).

4. Implications

Taken together, the evidence in Section 2 and the discussion in Section 3 above suggest that both environmental conditions and regulatory arbitrage might be important determinants of the location of DCCs, including in tax havens and/or in small middle-income countries with favourable local environmental conditions (see e.g. Iceland in **Figure 3**) that are attractive places for the location of data and cloud infrastructure. Below we summarise the potential implications of the uneven geography of digital infrastructures and why governments are starting to consider attracting DCCs as a strategic digital industrial policy tool.

***A new core-periphery structure*?**

A **'data haven hypothesis'** might partly explain the uneven concentration of digital infrastructure, similarly to how the 'pollution haven hypothesis' has been formulated to explain patterns of trade of green and brown products. Specifically, the pollution haven hypothesis posits that advanced countries may offshore activities that would not conform to their strict environmental regulations to mid and low-income countries (see Savona and Ciarli, 2020 for a selected review). Similarly, there is also a data haven hypothesis: these high data hub-intensive countries are those that offer either data privacy or looser environmental regulations, or more favourable tax regulations for investors and businesses[13] (see Scasserra and Foronda, 2022).

A data haven hypothesis might explain the occurrence of a new digital core-periphery global structure: the lack of scale may prevent smaller countries from becoming part of the digital core. Larger countries benefit from network externalities (i.e. the value of the digital services increases with the number of users), like those experienced by mobile phone users (Goldfarb and Trefler, 2018). It is possible, therefore, that big foreign businesses will remain the main technology developers, given that consumers are concentrated in developed countries,[14] and hence the returns on innovation are higher there. So, they may start considering small peripheral countries as main destinations to offshore energy-consuming data centres[15] with the aim of serving their home markets.

[13] This refers to Bank Secrecy Laws, for instance, and other regulations that vary across countries, do not allow the disclosure of costumer data and can lead to criminal penalties for those violating them.
[14] Goldberg and Reed (2023) argue that economic growth in larger economies relies less on international trade, as the concentration of consumers and income benefits developed countries by creating a large internal market.
[15] This can be large for the number of people that are there, hence the intensity can be high.

The geopolitics of digital infrastructure

Another implication of the offshoring of digital infrastructure is the increase of exposure to other countries. Most cloud centres are owned by businesses based in the US: Amazon, Microsoft, and Google, which account for **66% of the global cloud market**. This means that ***most countries rely on foreign data centres and cloud providers.*** The concentration of data centres' ownership may, therefore, reflect the underlying geopolitics, and its exposure to a foreign country's or private business economic shocks and policy priorities. More generally, the structure of the geopolitics of international trade can also play a significant role in driving the concentration of data centres and cloud services in specific countries. While the location of digital infrastructures may result from the differences in regulatory regimes discussed above, it can also be shaped by geopolitical distance and countries' alignment with the main digital geopolitical blocks. Lehdonvirta et al. (2023) show that a country's endowment of cloud infrastructure depends on the alignment with the US or Chinese cloud providers. This alignment (or lack thereof), in addition to security concerns, can reconfigure trade relationships. For instance, they show that Chinese and US-based multinationals own local cloud providers across 38 countries, and this relates to trade and security variables (conflict and cooperation alignment). Lehdonvirta et al. (2023) find evidence that countries import more from the country that owns relatively more domestic cloud service providers. That is, China exports more goods to countries where it owns more cloud service providers than the US. Also, conflict alignment (militarized interstate disputes) with a country (US or China) reduces the likelihood of hosting domestically its (US or Chinese) cloud service providers. Hosting DCCs may contribute to the geopolitical dominance of a few countries.

In sum, the concentration of data and cloud centres might also have adverse implications for a country's environment, data privacy, taxes, and position in the world economy (geopolitics). Trying to attract data and cloud centres by lowering taxes and reducing privacy or environmental standards can lead countries to a race to the bottom (Tarczynska, 2016), where they fail to create jobs, international trade and economic growth despite achieving a high presence of digital infrastructure in their jurisdictions.

5. Concluding remarks

In this paper, we show (**Figure 3**) that almost half of the data and cloud centres are based in the US, the UK, and Germany, which are the top digital service exporters. We also provide evidence that much smaller countries, all of which are considered tax havens, have a surprisingly large number of data and cloud centres for their size (**Figure 4**).

Data and clouds centres are critical inputs in the context of emerging digital automation, and we turned to the drivers and potential implications of their locations. We argue that ***the uneven location of data and cloud centres might be linked (and detrimental) to the environmental***

conditions or erode the tax base of the hosting countries. We also mentioned implications linked to the geopolitics of digital infrastructures.

There are, however, several areas where our understanding is limited, and hence further research is needed.

The construction of a more comprehensive dataset that includes information on the establishment dates of data and cloud centres would allow for an event study analysis. Such an analysis could explore the economic and trade impacts associated with the establishment of new data centres, potentially offering valuable insights into their impact on digital trade, taxes and the environment. Another limitation is the lack of information regarding the size, or capacity, of data and cloud centres. Future research could aim to gather size-related data, such as on storage and processing power, to better understand the role that scale plays in facilitating digital trade.

While this paper touched on security concerns, a more focused investigation into the geopolitical and security implications of data centre ownership and operation could offer new insights. Exploring the relationship between foreign direct investment (FDI) and data centre presence, as well as how multinational enterprises (MNEs) behave in data-centre-intensive economies, could deepen our understanding of how data and cloud centres drive trade and economic development. This paper primarily focuses on the location of data centres, but the ownership structure - especially in the context of multinational corporations - could provide further understanding of who controls them and how this impacts the role of data and cloud centres in the economy.

National governments might be constrained in playing a substantial governance role other than setting the regulatory framework. **International institutions**, however, such as the European Commission (The New Institute, 2023), or the increase of **data governance interoperability** (Bacchus et al., 2024) might help strengthen the role of national governments vis a vis private owners of data centres or cloud services and might have more leverage in setting regulations for data and environmental protection that might mitigate the possible detrimental effects of the concentration of digital infrastructures.

In sum, empirical evidence on the concentration of data and cloud centres is still in its infancy. The issues touched upon in this paper are complex, and relevantly intertwined, with each of them deserving a more detailed analysis. We hope to have identified some relevant links and raised questions that could pave the way for a much-needed further analysis on ***the determinants and implications of the uneven geography of data and cloud centres and more generally, on critical digital infrastructures.***

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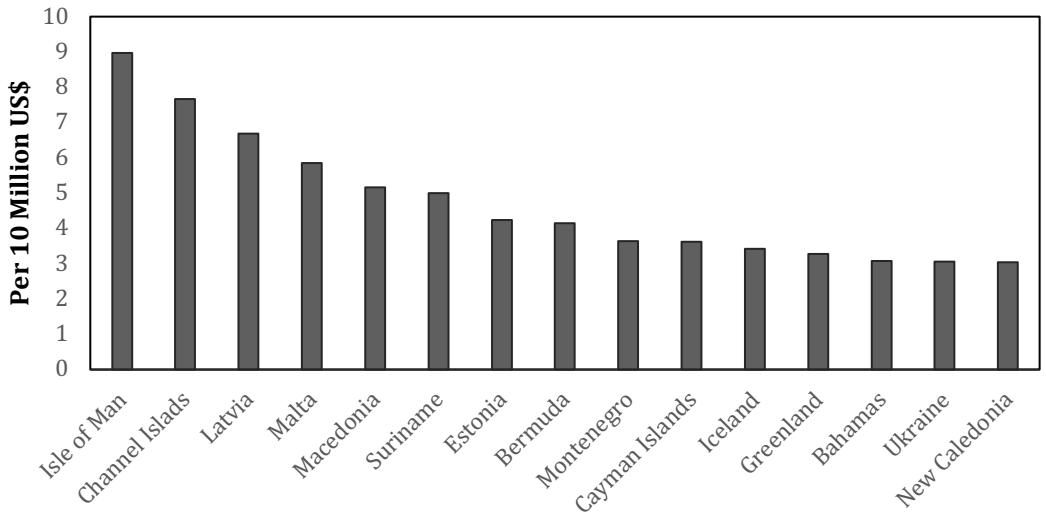
Appendix

Figure A1: Data Centres and Cloud Service Providers – Alternative Intensity



Notes: The graph shows countries with above three data centres and cloud infrastructures per ten million US$. Source: data on data centres and cloud infrastructures from www.datacentermap.com; data for 2018 GDP in US$ from IMF, WB, and UN. Own calculations. Non-available GDP data for Netherlands Antilles, Laos, Jersey, Palestine, and Guernsey.