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The Uneven Geography of Digital Infrastructure

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Key points

- Data has become an essential production input and is increasingly stored in data and cloud centres (DCCS) rather than in firms' on-premises equipment.
- DCCS are concentrated in a few countries that are the top digital exporters, such as the US, UK and Germany.
- However, the highest intensity of per-capita (or per GDP) DCCS are found in a few small countries specialising in financial services exports and are known to be tax havens.
- DCCS' location may reflect economic and geopolitical security concerns or alignment with US and China trade blocks and be associated to regulatory arbitrage, be it on fiscal regimes, environmental or data regulations.
- Decisions to invest or attract Foreign Direct Investments in DCCS should be based on evidence of their environmental footprint, the effects on labour markets, such as quality of job creation, and compliance with regulations.

Introduction

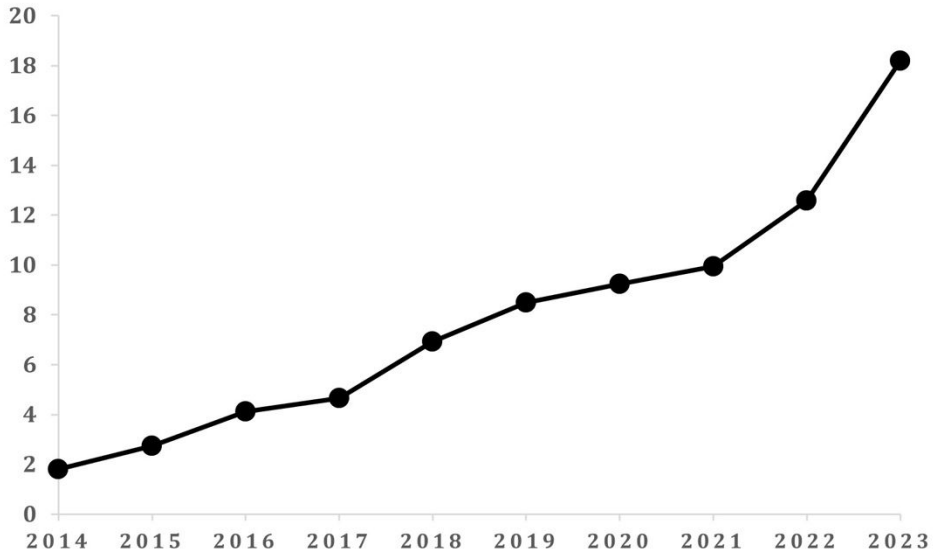
Data centres and cloud service providers (DCCS) have become an essential part of the digital physical infrastructure, alongside optic fibres, submarine cables, etc. They are the tangible component of investments in emerging digital technologies such as data acquisition, data management, computing and artificial intelligence, that are intangible in nature.[1]

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. While there has been a large increase in private spending for the construction of data centres in the US, - which has increased from $1.8 billion in 2014 to $18.2 billion in 2023 (see Figure 1) - there is also a trend of both outsourcing and offshoring data-intensive processes and services to external cloud service providers and data centres**.** According to the IMF *"Cloud computing services, defined as "computing, data storage, software, and related IT services accessed remotely over a network,*

[1] Savona, M. Ciarli, T., Steinmueller E., Vannuccini, S. 2022. The Design of Digital Automation Technologies: Implications for the Future of Work. CESifo EconPol Forum 23 (5), 4-10.

supplied on demand and with measured resource usage that allows charging on a pay-per-use basis"[2]*, are increasingly used to replace ownership of on-premises IT equipment.*" Yet, we know little about the determinants of their location.

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



Data source: US Census data - Construction Spending

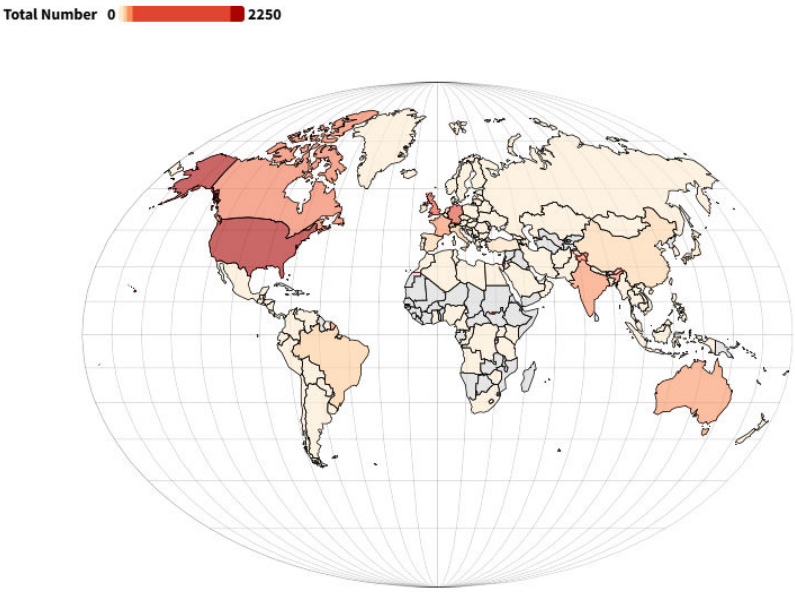
This Briefing Paper focuses on the geographical distribution of data centres and cloud service providers. We find, perhaps not unexpectedly, that a high share of data centres are located in the US, Germany, and the UK, which are also relatively large digital services exporting countries. However, interestingly, when looking at the intensity (i.e. per head, or per GDP) of data and cloud centres, it transpires that it is highest in a few smaller countries which specialise in financial services exports and are often referred to as 'tax havens'. We discuss the potential drivers and implications of the location and uneven geography of data centres and cloud providers for businesses and countries.

The geography of digital infrastructure

In Figure 2 we map the number of data and cloud centres. Countries that have a higher number have a darker red colour. We see that the geography of data and cloud centres is uneven, with significant heterogeneity across counties.

[2] IMF, OECD, UN, WTO, 2023. Handbook on Measuring Digital Trade (Second Edition).

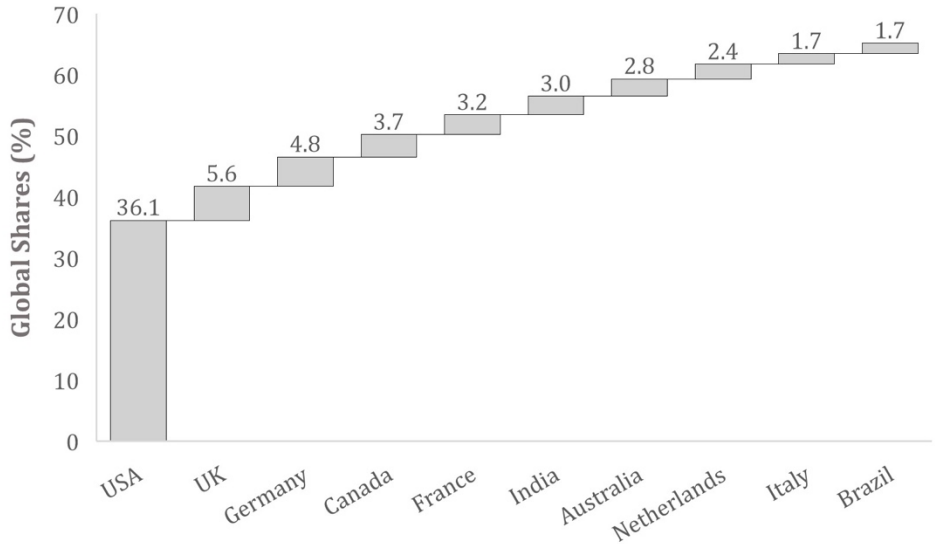
Figure 2: Total Number of Data Centres and Cloud Service Providers



Notes: This figure maps the total number of data centres and cloud service providers. Darker orange countries have a high number of data centres and cloud service providers. In grey 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 their global shares of data centres and cloud service providers. The US, Germany, and the UK 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 these top 3 countries are among the top exporters of (digital) services worldwide.[3] The data also reveals the concentration of DCCS. The US alone accounts for one in three data and cloud centres worldwide. Most of the top 10 countries are large and advanced countries, except for India and Brazil, which are large emerging markets, and the Netherlands, which is a small, advanced country.

Figure 3: Data Centres and Cloud Service Providers – Shares



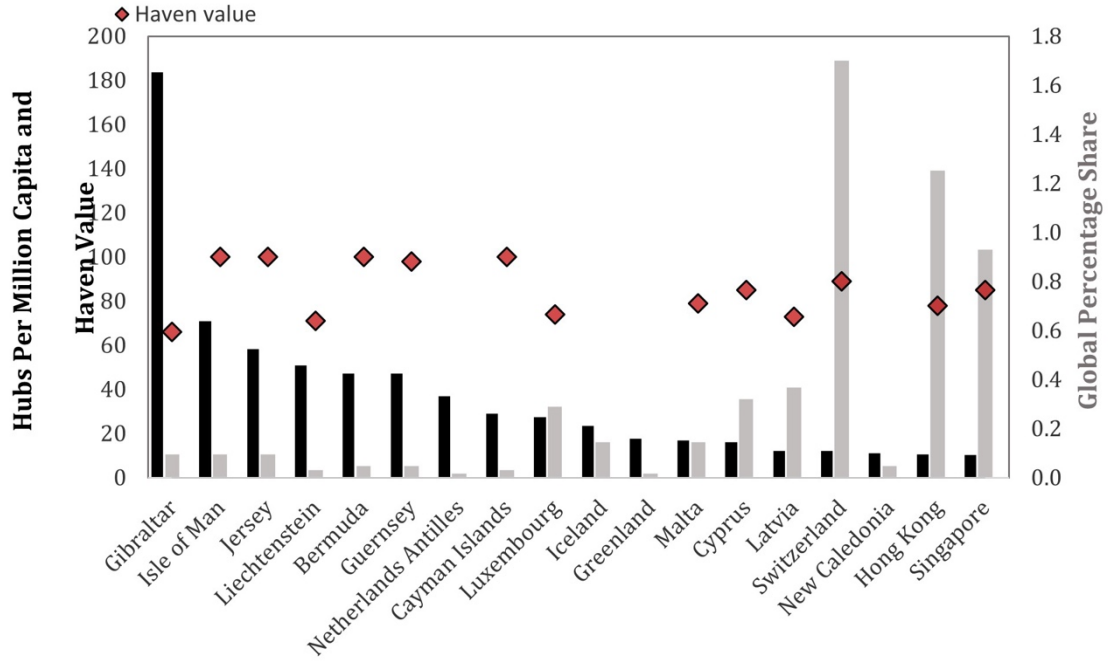
[3] UNCTAD, 2023. Total trade in services.

Source: 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 size differences across countries. Figure 4 considers the intensity of digital infrastructure. It shows the number of data centres and cloud infrastructure per million people. When it is standardized by 2022 population figures, the intensity of digital infrastructure is substantially higher in a particular subset of small countries. The countries in Figure 4 are all small, relatively advanced countries, many of which are also those that are considered tax havens (i.e. they have a Haven Score which is close to 100).[4]

Some of them - Switzerland, Hong Kong and Singapore – are also highly ranked in terms of their share of global data centres, albeit not being included in the top ten countries in Figure 3. Germany, the UK, and US do not appear in Figure 4, as they have only 4, 5, and 7 data centres and cloud infrastructures per million people, respectively.[5]

Figure 4: Data Centres and Cloud Service Providers – Intensity



Source: 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 the Netherlands, Antilles, Iceland, Greenland, and 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. The countries with the highest shares are not those that show high intensity, which suggests that there are different drivers behind the location of data centres.

[4] 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 the 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.

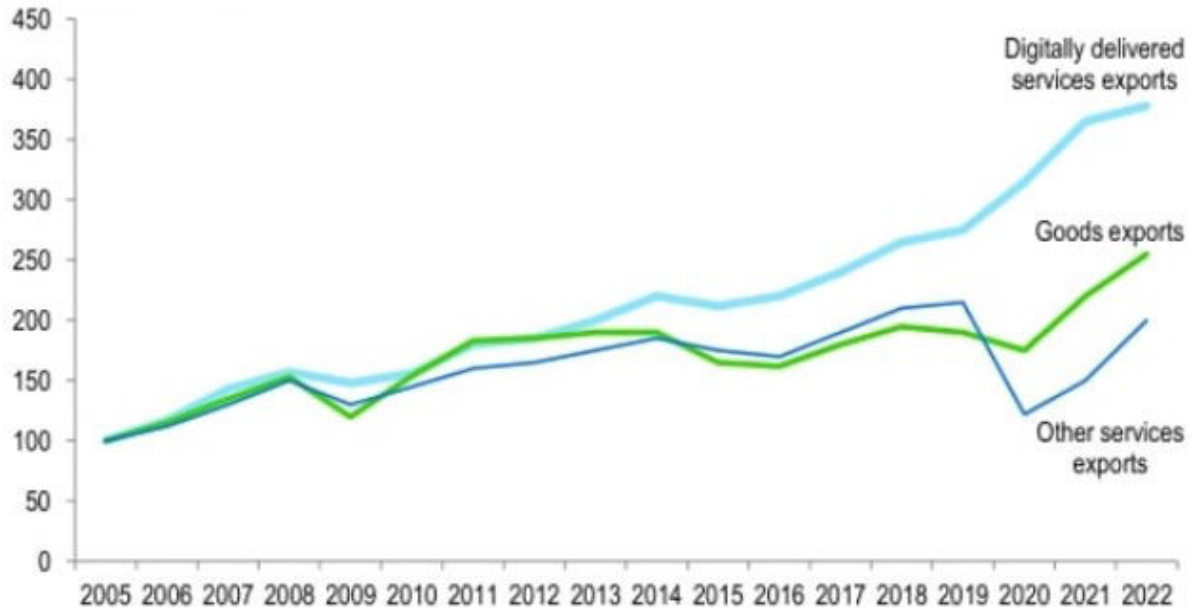
[5] This picture does not change if we measure intensity using GDP values in the denominator – see Figure A1 in the Appendix[5]. Isle of Man, Bermuda, Latvia, Cayman Islands, Iceland, Greenland, Malta, and New Caledonia appear in both figures: what we capture is not driven just by the low population density nor by cross-country differences in population.

Does the location of digital infrastructure matter?

Trade increasingly depends on the presence of digital infrastructure, such as data and cloud centres, as trade becomes more digitised. For example, the number of internet hosts (internet penetration) in a country has often a strong positive association with international trade in services.[6]

The share of services in total world exports has increased significantly over the last twenty years - it peaked at 25% in 2019, up from 19% in 1982, and stood at 23%[7] in 2022. In good part, as can be seen in Figure 5, this increase is due to the rise of digitally delivered services.[8] This is also consistent with Figure 3 where the top digital exporters account for the largest shares of digital infrastructures.

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



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

Why might the location of data and cloud centres matter? On the one hand, if businesses can access data and cloud centres from any country in the world, co-location offers no advantage to businesses. Hence, digital trade policy should focus on barriers that limit access to data and cloud centres. In this case, the concentration of DCCS in a few countries would not be of concern.

On the other hand, the location of data and cloud centres may matter due to cross-country differences in data flow and adequacy regulations which are location-specific. For instance, the EU's General Data Protection Regulation (GDPR) imposes strict rules on transferring personal data outside the EU, only allowing it if the receiving country has been deemed to offer "adequate" data protection or if specific safeguards are in place. This means that a U.S. business selling to customers in a "non-adequate" country may face significant legal challenges if it stores its data in the EU, as these regulations could restrict the transmission of data to and from its primary market. Therefore, businesses may need to carefully consider where to locate their data and cloud centres to comply with local regulations and ensure efficient data flow.

[6] Freund, C, and Weinhold, D. 2002. "The Internet and International Trade in Services." American Economic Review, 92 (2): 236-240.

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

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

There are also technological factors which may drive co-location.[9] Both buyers and sellers of digital products use broadband and large servers to perform digital transactions that generate large data and need to be processed and stored efficiently, reliably and promptly. Hence, the proximity of businesses to digital infrastructure is key as it can increase data speed and network latency. It follows therefore that the cost and quality of the services (due to speed and reliability) may depend on where data and software are stored. For instance, if a US business sells its products mostly to domestic customers it would not use a European data centre, as this would mean that the transaction-generated data would need to travel from a US-based seller's device to a US-based buyer's device after first crossing the Atlantic Ocean multiple times through submarine cables.

Digital services trade relies on the investment capacity in physical digital infrastructure that supports cross-border data flows, including submarine cables, optic fibres, and, more recently, data centres and cloud storage of data and software. Countries that engage heavily in digital activities might establish data and cloud centres to support the activities they already perform productively but also by establishing data and cloud centres they help grow those activities. Arguably, therefore, one of the factors contributing to the differences in the trends across digital services exports may be the investment in digital infrastructure.[10] The causality could run, however, the other way around too, that is high competitiveness in digital trade could give rise to data centres in a country.

To better understand this, we unpack the different components[11] that make up digitally delivered services exports in Figure 6. The top panel provides the decomposition for all countries, the bottom panel provides the decomposition for those countries identified as intensive in data and cloud centres (as given in Figure 4). The right-hand figures, for each panel, show that there has been a rise in all digital services (relative to 2005).

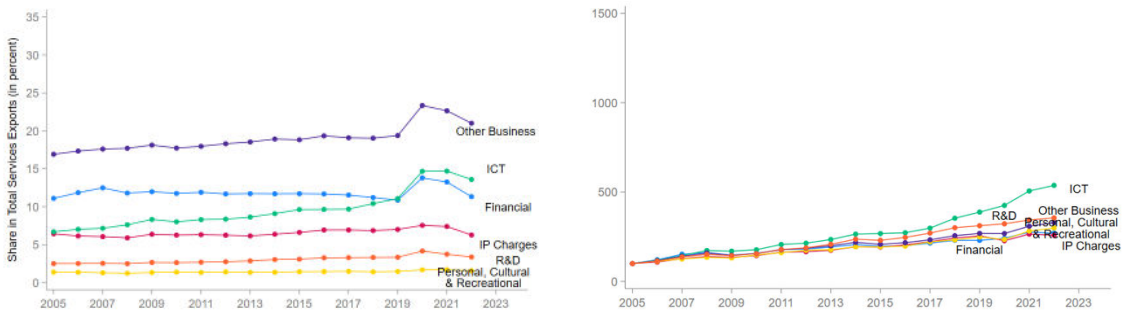
[9] There are several blogs from experts in this area that support this argument. See for instance here: https://www.datum.co.uk/insights/blog/why-location-matters/

[10] For a more detailed discussion on the benefits of digital infrastructure for governments see a recent IMF report.

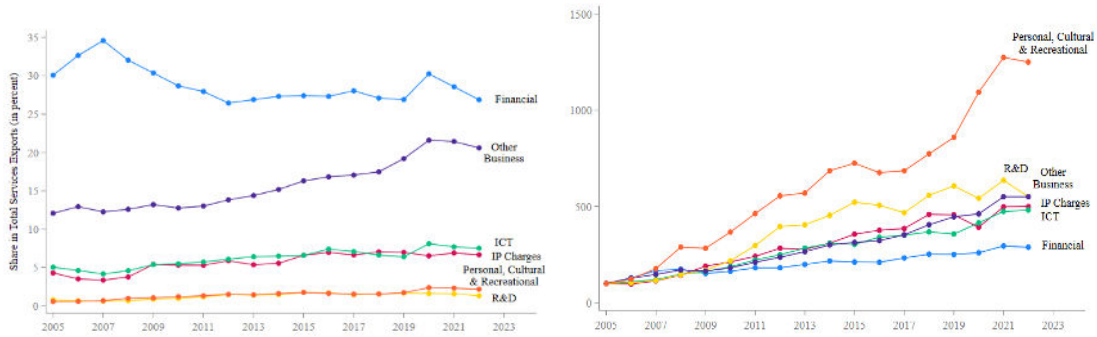
[11] See table 4.1 here for a more detailed breakdown of digitally delivered services, according to the WTO definition.

Figure 6: Data and cloud centre intensive countries, shares (left) and trends (right) with base year 2005=100

Panel A: World



Panel B: Data and cloud centre-intensive countries



Source: data from UNCTAD, own calculations. Notes: All the lines represent different types of digitally delivered services according to the WTO definition.[12] 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.

Panel A shows that for the world as a whole, business and ICT services hold the largest share of digital exports, and the latter saw the largest growth in more recent years, likely driven by technological advancements, technology transfers, and the shift toward online services accelerated by the COVID-19 pandemic. Conversely, financial services are the largest component of digitally delivered services in DCCS-intensive countries, which is consistent with the fact that many of these countries are considered tax havens. Interestingly, personal, cultural, and recreational (PCR) services are the component with the highest growth, though this is consistent with this sector showing a low initial share in 2005. Other business services—such as legal, accounting, management consulting, advertising, market research, and engineering services—are the second largest component of digital services in DCCS-intensive countries. These may well be supporting financial services and driving the digital exports in these countries. Further research isolating the specific effects of data centres would clarify their impact on global digital trade patterns and is part of a research agenda on this topic.

Determinants of the location of digital infrastructure

When choosing the location of data and cloud centres, on the one hand, the aim will be to minimize costs and to be close to the users of their services, on the other hand, there may be other factors, be these regulatory or geo-political, which impact on these decisions.

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

It is not surprising, therefore, that the countries in Figure 3 are relatively large and rich, as consumers and businesses tend to be concentrated there. This is particularly important for digital services and cloud centre providers. Larger countries benefit from network externalities (i.e. the value of the digital services increases with the number of users). For example, in a country with a high concentration of users, a digital platform providing services such as a social media network or e-commerce becomes more valuable to each user because there are more people to connect with or sell to. This effect, similar to how mobile phone networks become more valuable as more people are connected,[13] means that larger markets can drive more demand and usage. Therefore, market size is a key determinant for the location of data and cloud centres, as it helps maximize the reach and efficiency of these services.

The costs of operating and establishing a data and cloud centre determine also whether a location will be able to attract data and cloud centres. 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."[14] Cost differences are reflected in where data centres are located. A colder climate, the availability of energy and 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).

Some countries may face lower costs than others. Digital infrastructure relies heavily on natural resources (water) and environmental conditions (cold weather). Over the past year, Google's hyper-scale data centres used to cool their servers an average of 2.1 million litres of water a day.[15] 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.

Differences in regulatory regimes might drive the location of data centres. For instance, data privacy and consumer rights regulations can create incentives for businesses to choose to use data and cloud centres that are close to them and the market they serve.[16] Further, businesses as well as high-income individuals choose to store their assets and data related to them in jurisdictions that offer lower taxes and financial privacy.[17] Indeed, the bottom panel of Fig 6 indicate the importance of both digitally delivered financial and business services for the DCCS countries, and these may be related, and their rise is jointly determined. Another instance where regulations drive the location of data and cloud centres is environmental regulations that can change the costs of establishing digital infrastructure.

IP and other intangible capital which are part of digital services and are stored in cloud and data centres, are prone to tax avoidance as it is hard to measure and enforce the tax law.[18] Empirically, the relationship between tax havens and digital services (such as IP) has been explored for Germany[19] and for Italy,[20] who have emphasised the role that multinational firms play in strategically shifting profits offshore. This has been

[13] Goldfarb, A. and Trefler, D., 2018. AI and International Trade. National Bureau of Economic Research, Working Paper Series: 24254.
[14] United States Chamber of Commerce and Hunton & Williams LLP, 2014. Business Without Borders: The Importance of Cross-Border Data Transfers to Global Prosperity.
[15] Zhang, 2024. Data Center Water Usage: A Comprehensive Guide
[16] Bacchus, J., I. Borchert, M. Morita-Jaeger, J. Ruiz Macpherson. 2024. Interoperability of Data Governance Regimes: Challenges for Digital Trade Policy. CITP Briefing Paper (2024, forthcoming).
[17] Ferracane, M., B. Hoekman, E. van der Marel, F. Santi, 2023. Digital Trade, Data Protection and EU Adequacy Decisions. CIP Working Paper n. 6 (October 2023).
[18] Haufler, A., Schindler, D., 2023. Attracting profit shifting or fostering innovation? On patent boxes and R&D subsidies, European Economic Review, Volume 155, 104446; Alstadsæter, A., Barrios, S., Nicodeme, G., Skonieczna, A. M., Vezzani, A., 2018. Patent boxes design, patents location, and local R&D, Economic Policy, Economic Policy, Volume 33, Issue 93, January 2018, Pages 131–177
[19] Hebous, S., and Johannesen, N, 2021. At your service! The role of tax havens in international trade with services. European Economic Review, Volume 135, 103737, ISSN 0014-2921.
[20] Accoto, N., Federico S., and Oddo, G., 2023. Trade in services related to intangibles and the profit shifting hypothesis, Temi di discussione (Economic working papers) 1414, Bank of Italy, Economic Research and International Relations Area.

generalised and corroborated in more aggregate data and for a larger set of countries[21]. Furthermore, low corporate tax regimes, and particularly patent boxes,[22] may result in (IP-related) profit shifting rather than increased incentives for innovation.[23]

The location of data centres and cloud providers may also reflect the geopolitical structures of alignment[24] with the main digital geopolitical blocks. For instance, a country's endowment of cloud infrastructure may depend on the alignment with the US or Chinese cloud providers.[25] This alignment (or lack thereof), in addition to security concerns, can reconfigure trade relationships. In particular, evidence shows 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. As a result, digitisation, trade and geopolitics are very closely related, and the establishment of data and cloud centres depends crucially on international relations.

Implications

In this section of the paper we consider in what way the location of DCCS may matter, and some of the possible consequences of policy interventions.

1. Building on the preceding discussion, it is clear that the presence of DCCS may be more than simply a reflection of countries relative strength in digitally delivered trade, especially in services, but may also be a driver of competitiveness. More research on this is needed but to the extent that this may be the case, and given the substantial costs associated with DCCS there may be a role here for policy intervention.
2. However, there are concerns regarding the efficacy of the subsidies received. Since 2015 there have been $10 billion data centre deals in the US that have received at least $811 million tax abatements for creating 837 permanent jobs.[26] This amounts to 1 million per job. In the US, substantial tax relief has been offered to attract data centres. Alabama, for instance, provides abatements for centres investing $400 million and purportedly creating just 20 jobs with annual compensation of $40,000. In aggregate, such incentives often fail to generate net job creation or economic growth.[27] Instead, they reallocate jobs across states without promoting efficient resource use. While this is casual empiricism and based on newspaper reports it does raise questions about the role of data centres as a cost-effective tool of economic development.

3. An implication of the offshoring of digital infrastructure is increased exposure to other countries. Most cloud centres are owned by businesses based in the US: Amazon, Microsoft, and Google.[28] As a consequence, most countries rely on foreign data centres and cloud providers, which in turn may impact countries' supply chain resilience and economic security.

   To some extent, this may be mitigated by the concentration of ownership reflecting underlying geopolitics. For instance, as we discussed earlier, the presence of Chinese or US cloud providers contributes to a

[21] Santacreu A. M., 2023. International Technology Licensing, Intellectual Property Rights and Tax Havens. forthcoming at The Review of Economics and Statistics
[22] Patent boxes are used to incentivise business to invest in R&D by taxing patent revenues at lower tax rates than other business revenues.
[23] Haufler, A., Schindler, D., 2023. Attracting profit shifting or fostering innovation? On patent boxes and R&D subsidies, European Economic Review, Volume 155, 104446, https://doi.org/10.1016/j.euroecorev.2023.104446.
[24] Bacchus, J., I. Borchert, M. Morita-Jaeger, J. Ruiz Macpherson. 2024. Interoperability of Data Governance Regimes: Challenges for Digital Trade Policy. CITP Briefing Paper (2024, forthcoming).
[25] Lehdonvirta, V., Boxi, W., and Hawkins Z., 2023. Cloud empires' physical footprint: How trade and security politics shape the global expansion of U.S. and Chinese data centre infrastructures.
[26] Jeans, D., (2021). Data in the dark: How big tech secretly secured $800 million in tax breaks for data centers. Forbes.
[27] Slattery, C., and Zidar O., 2020. "Evaluating State and Local Business Incentives." Journal of Economic Perspectives, 34 (2): 90–118.
[28] Large platforms such as Amazon, Microsoft, and Google account for 66% of the global cloud market.

country's trade relationship with the US and China. There is also evidence that trade relationships translate into political alignment between the trade partners.[29]

Dependence on foreign countries and businesses also raises questions concerning local values, differences in citizens' concerns regarding privacy or the natural environment, and the incentives to create jobs for domestic workers. For instance, Pat Garofalo, a director of the American Economic Liberties Project, argues that residents question the quality of jobs data centres create and instead emphasize the environmental risks they bring in.[30] Of course, these are questions relevant to many aspects of supply chain offshoring.

4. Countries may attract data and cloud centres by offering data protection or more favourable environmental and tax regulations to investors and businesses.[31,32]
    a. To the extent that high digital infrastructure intensity is the result of the tax breaks or the privacy their financial sector offers to investors, this may contribute to tax base erosion globally.
    b. To the extent that it is driven by favourable environmental regimes, there may be environmental consequences. Given that data centres' cooling systems rely extensively on water and that water is a scarce resource,[33] there are concerns about the use of this valuable resource and the environmental implications of the extensive presence of data and cloud centres.

Conclusion

We have shown that almost half of all data and cloud centres are based in the US, UK, and Germany and that these are the top digital service exporters. We also show evidence that much smaller countries, considered as tax havens have disproportionately high number of data and cloud centres relative to their size.

Data centres and clouds are critical inputs in the context of emerging digital automation, hence, it is important to understand their drivers and the potential implications of their location. While driven by a mix of competitiveness, regulatory and economic security considerations, the uneven location of data and cloud centres may also be detrimental to the environment or erode the tax base of the countries that host data centres.

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

1. The construction of a more comprehensive dataset that comprises information on the establishment dates of data and cloud centres over time would allow for event study analysis. Such 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 the scale plays in facilitating digital trade.

2. 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. The ownership

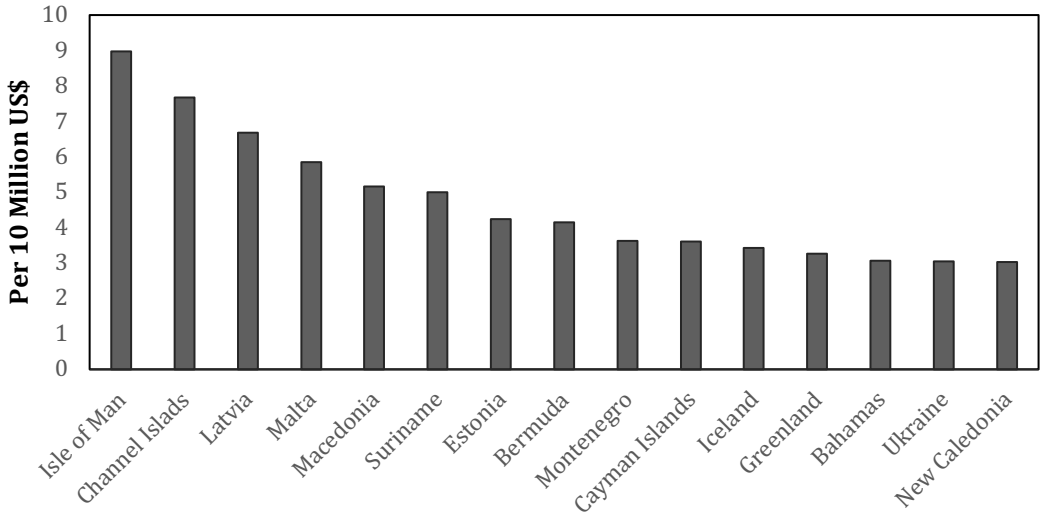
[29] Kleinman, B., Ernest L., and Redding, S. J., 2024. "International Friends and Enemies." American Economic Journal: Macroeconomics, 16 (4): 350–85.
[30] Jeans, D., (2021). Data in the dark: How big tech secretly secured $800 million in tax breaks for data centers. Forbes.
[31] This refers to Bank Secrecy Laws, for instance, and other regulations that vary across countries, do not allow the disclosure of costumer data and can lead to penalties for those violating them.
[32] Scasserra, S. and Foronda, A. B., 2022. Banking on data. The Transnational Institute. The Transnational Institute.
[33] Evidence shows that by 2050 more than half of the population will live in water-stressed areas (Schlosser et al., 2014).

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.

In sum, empirical evidence on the concentration of data and cloud centres is, relatively speaking, still in its infancy. The issues touched upon in this brief paper are complex, and relevantly intertwined, with each of them deserving a more detailed analysis.

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.