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What Should Economists Know About the Cloud? A Literature Review on Digital Economics

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What Should Economists Know About the Cloud? A Literature Review on Digital Economics

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Abstract

The climate of technological innovation has presented the world with many solutions, but at the same time, many issues follow. This paper discusses several elements of the backbone network and data centers to encourage researchers to work on this subject and dig deeper into the economic impact, regulation, competition, etc. This paper should be read as a simple guide to this complex industry.

Keywords : Cloud Technologies, Data Center Localization, Data Storage and Computing, Personal Data

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1 Introduction

The increasing usage of platforms and the Internet has introduced new requirements for these actors to maintain a high level of digital services to their consumers. Among these needs, there is network and data storage and computing. Firms started to supply their needs by using IT infrastructure on-premise and hiring to subsidize the hardware requirements. However, in 2021 e-commerce has reached 8.891\$ billion on worldwide sales and 4.66 billion Internet users.^{1,2} Under such circumstances as well as seeking more reliable services at lower prices, firms can not bear the load of users and data. Hence, in the last years, firms have introduced strategies for of deporting data storage and computing to the Cloud. In this paper, we discuss the market of Cloud and data center providers as well as related business models. We also review theoretical and empirical literature on the relation and effects of the usage of data centers and Cloud technologies in different sectors and consumer behavior. We identify several data centre implementation strategies and out-coming regulation issues that arise from them. Last, we would like to highlight the need for further research to better understand the still-blurred parts of this market.

It is essential to clear out any ambiguity between Cloud services, data centers and on-premise. Data centers are one or a group of physical buildings, home to a significant number of servers which provide storage and computing services. On-premise is a sub-group of the previous one and defines the servers owned by the firm. Last, the Cloud is a service of computer system resources, usually on demand, offering data storage and computing. Cloud providers either have their data centers or go through data center providers to host their hardware and software. Thus, data centers are nothing less than on-premise for Cloud providers themselves.

The Cloud providing and data centers market is an oligopolistic model with three main actors: Amazon Web Services (AWS), Azure, Google Cloud and two with lower market shares than the previous, Oracle Cloud and IBM Cloud, supplying the consumers in the presented order. The service models proposed by Cloud service providers are mainly threefold : IaaS (Infrastructure as a Service), PaaS (Platform as a service) and SaaS (Software as a Service). For instance,

¹<https://www.statista.com/statistics/379046/worldwide-retail-e-commerce-sales/>

²<https://www.statista.com/statistics/617136/digital-population-worldwide/>

they offer tools for data storage, network and compute power with software management. The number of tools provided to consumers goes up to 600 and is aimed at many users from all sectors, such as developers, data scientists, managers, researchers, etc.

Byrne *et al.* (2018) find that prices of Cloud services have decreased quite quickly and investment in IT technology and infrastructure, as well as Cloud use, have faced a remarkable growth. On the other hand, digital goods such as data are characterized by very deficient search, replication and transportation costs (Goldfarb and Tucker, 2019) making these components of data storage and computing easily accessible for firms. However, Jin and McElheran (2017) disentangle the benefits according to firm age, showing that older firms have little to no profit while young firms are associated with a higher estimate.

Cloud providers tend to apply similar business models with very few differences. Even though prices can be public, pricing strategies are characterized by negotiation, leading to different prices for different firms. However, the most popular model used is "pay-as-you-go", allowing firms to pay post usage the tariff corresponding to their actual consumption. There can also be found pricing for a single use or subscription on a monthly bases. Cloud providers will apply different strategies to attract different types of consumers, such as special offers for start-ups or discounts on newly purchased products for historical clients. It should be mentioned that even though prices are different from one provider to the other they tend to be dependent on a few characteristics such as the storage location chosen by the client as well as the number of locations if data replication is required, hardware configuration (CPU, graphical processing, etc.) and software configuration (automation, maintenance, network, security, etc.). Despite these similarities, to our knowledge, there is no standardization in pricing among Cloud providers. Thus, in lack of data on prices, it is tough to point out whether some consumers are favored over others or even assess the distribution of profits between providers and consumers (Greenstein, 2020).

Data center location remains an understudied topic. Each actor of this equation has its own strategies in terms of choice of location. On the one hand, Greenstein and Fang (2020) unveil that Cloud and data center providers consider many factors before building their infrastructures, such as population density, real estate market, weather, electricity prices, etc. Furthermore,

servers have a lifespan of three years which leads to an important turnover and makes providers susceptible to sales taxes. Last, they will tend to get as close to their consumers as possible and seek a strong network (Internet exchange points, satellite, submarine cables). This last strategy is backed by Blum and Goldfarb (2006) by finding that physical distance reduces trade even in online products and services that should be free of trade costs. On the other hand, firms might be applying two main strategies: choosing a data center closer to their consumers to provide the shortest latency or going with a historical partnership that might be more reliable or less expensive. Regarding geographic locations, Cloud infrastructure services are divided into physical areas where Cloud resources are located (AWS - 25, Microsoft Azure - 54, Google Cloud - 25). However, the information on the location of servers remains approximate to the region level and in some way a black box.

Data center location, hence data localization, is reasonably related to regulation as it implies privacy and security issues (Goldfarb and Treffer, 2018). Firms handling personal data, as well as Cloud providers and data centers storing and computing them, have raised many questions as to comply with the local regulation on personal data or the regulation of the country of origin of the consumers. As technology and infrastructure are developing very fast, regulators worldwide struggle to keep up with it. For instance, through this technology, personal and sensitive data of European users are stored and computed in and with US technology on US ground creating many regulation issues. In terms of personal data protection, data center providers, Cloud providers, and firms have been impacted by the Cloud Act and the CCPA (California Consumer Privacy Act) for US laws, and the GDPR (General Data Protection Regulation) and from January 2022 the DSA (Digital Service Act) for EU laws. The laws mentioned above are designed to give consumers more control over their data, protect data sovereignty and help firms develop in a more respectful environment. Despite the tremendous effort, there is still a long way to go to achieve more relevant laws and discuss the trade-off between ex-ante and ex-post regulation.

This literature review will attempt to contribute to the research on the components of the backbone network : connection infrastructure (routers, switches and cables), Domain Name System (DNS), Content Delivery Network (CDN), Internet Exchange Points (IXP) and finally data center infrastructure. This paper's organization follows the route of an Internet query, from

the request to the browser to the response from the data center with a simplified approach.

2 Architecture

In this paper, we will discuss the backbone network with a focus on Cloud infrastructures, particularly the route of data from a personal computer to a data center. We will divide this into two parts the hardware part of the infrastructure and the software.

First, we analyze the physical route for the data from the personal computer and all devices such as printers, security cameras, smartphones and all others connected to the Internet in a household. All these components are connected to your Internet modem either by Ethernet cable or wireless, creating a LAN. From this Local Area Network, Internet queries go from your device to your modem. This last one redirects the request towards other routers/switches till the targeted IP address is reached. For this path to be completed, the data goes through different types of connection infrastructure, mostly optic-fiber, Internet Exchange Points (IXPs) and finally reaches the data center where the data is stored. This path is taken every time a query is done on the Internet. However, this path is unique and different for each IP address. Once the data center is reached, it will send back the required data, which will follow the same previous path.

The software component uses the hardware layer to provide the requested data from the user. If the user types "www.ec.exemple.com", the browser sends a request to the DNS to obtain the corresponding IP address. Once this step is completed, the browser requests the IP address to get the website's content. The response comes back from the same path as the website content: images, text, code, technical content, etc. However, the response content might need additional requests. Thus the same path is followed.³

These two layers are perfectly intertwined, but response time, also called latency, is critical for both users and providers. To reduce latency, Content Delivery Networks (CDNs) were created so that data could be closer to the user. Nonetheless, it is up to the Domain Name System (DNS) to reply with the nearest CDN, hence the IP address that provides the data the

³To simplify the description and focus on only the significant components, we do not include further information about other hidden faces of the network.

quickest. It is essential to mention that the best result doesn't necessarily correspond to the shortest geographical distance but mainly to the best-served server (either a CDN or a data center) closest to the user.

3 Hardware components

3.1 Routers, Switches, LAN and WAN

A switch allows all a firm's devices (computers, servers, printers, etc.) to communicate and share information. On the other hand, a router is an ensemble of switches connected to give a larger network.⁴ This first layer of connections makes the Local Area Network (LAN), also called the personal network. Furthermore, the Wide Area Network (WAN) depicts a more extensive network on a larger geographic scale, for instance, the connection between a modem and the Internet.⁵

Roberts (2000) describes the growth of the number of computers and the Internet as a "Beyond Moore's Law" phenomenon. Hence, the speed capacity of routers and switches had to follow the same trend. In the last quarter of 2021, the switch market reached revenues of \$8.5 billion with an 11.8% growth. For the same period, the router market went through a 7.0% growth, giving revenues of \$4.6 billion. According to the International Data Corporation (IDC), the top switch and router providers are Cisco, the market leader, followed by Huawei, Arista Networks, H3C and HPE.⁶

With the evolution of needs from the consumers and Cloud providers, these routers and switches provider quickly became providers of connection technologies. To illustrate the interoperability between these providers and data center providers, Cisco is a great example offering switches, routers, cybersecurity and IoT. They work with Cloud providers such as Azure, AWS and Google Cloud, providing them with various products and services, many of which the end consumer most of the time isn't aware of using Cisco. Azure uses them for services such as Azure Stack, a hybrid Cloud computing solution offering Azure function for firms and organ-

⁴What is a Switch vs a Router? - Cisco

⁵WAN vs. LAN - Google Nest

⁶IDC's Worldwide Quarterly Ethernet Switch and Router Trackers Show Strong Growth in the Fourth Quarter of 2021 - IDC

isations with their own on-premise data centers. This service can be beneficial for sensible data whose storage is framed by regulation (for example, the GDPR and personal data); vertical industries or governmental data; and connectivity latency for remote locations.⁷ Furthermore, Cisco services are used by AWS to allow their consumers to easily create WANs, migrate quickly and safely from on-premise to the Cloud, setting up VPN firewalls to support the great load of "working-from-home" as the world has come to know the last couple of years.⁸ Much like its other competitors, Google Cloud has implemented the Cisco solutions going from routers for big firms to distance co-working to managing several apps and much more.⁹

3.2 Cables

Cables, either underground or underwater, are a crucial component of the Cloud architecture. Cables have ensured communication since the second half of the nineteenth century, starting with Morse code and telegraph, to landlines, Internet, Cloud, etc. This paper will particularly address the underwater cable system.¹⁰ The first cables were the telegraphic ones which laid the way for discovering and testing the suitable materials from wood derivatives (gutta percha) to the short-wave wireless technology to vacuum-tube transmitters, which increased privacy and reliability (Finn, 2013). Telephone cables are the second type providing the first telephonic connections, followed by the optic fibre created in 1970 (Finn, 2013). This new technology coincided with and allowed the rise of the Internet (World Wide Web).

The first underwater cable in the history of humankind was laid in 1850 between England and France. The first transatlantic cable connected Ireland and Newfoundland in 1858 to provide telegraph communication (Hunt, 1997). Since then, 486 cable systems have been on the seabed worldwide, equivalent to more than 1.2 million kilometres.

Since the 1970s, public network operators have dug underground or underwater trenches to lay lines between two or more locations. The higher cost of the operation was labor and the entry cost of laying the lines. The operators benefited from economies of scale in case of adding cables to existing lines. However, some already-in cables weren't used and became

⁷Cisco Integrated System for Microsoft Azure Stack Hub

⁸Cisco Solutions on AWS

⁹Cisco and Google Cloud

¹⁰Submarine Cable Map 2022

called "dark fiber". Initially, operators opposed sharing these cables (due to fears of a decrease in performance quality) until the private demand grew bigger. Nowadays, dark fiber cables can be bought or rented, leading to a new market. Whereas a complicated valuation characterizes this asset as it does not generate immediate value to the buyer, its entry cost is very high due to the lighting cost (Kenyon and Cheliotis, 2002). In addition, a fiber line leads to purchase and management costs for both ends. Nevertheless, firms gain significant advantages such as complete autonomy, better security and near limitless scalability.

With the increasing usage of the Internet and online firms, the need to connect Cloud infrastructures has also risen. GAFAM (Google, Apple, Facebook, Amazon, Microsoft) started creating their fiber channels by either purchasing or renting dark fiber, laying fiber lines in collaboration with network operators or other firms or laying their lines.¹¹ The latest strategy provides more independence and expands their fiber channels to get the closest route from one data center infrastructure to the other, leading to shorter latency and better service for different types of consumers, such as high-frequency trading.

3.3 Internet Exchange Points (IXP)

Internet Exchange Points (IXP) are physical locations that allow the connection between networks and ISPs¹²). These locations were initially situated at the intersections of fiber optic cables and later on based on economics of scale considering other Internet components such as fiber access and the areas of large cloud service providers Blakley (2021). Furthermore, IXPs play an essential role in the backbone of the Internet, allowing data to travel fast from one point to another, finding the closest IXP, thus reducing latency.¹³ In addition, Chatzis *et al.* (2013) separate the market into two central parts with very different business models. First, the European market, which is more non-profit based; second, the United States market with a more for-profit approach.

¹¹Facebook to Expand Planned Undersea Cable Network in Africa

¹²ISPs mainly provide Internet connection to consumers as well as other services such as domain name registration, web hosting and colocation.

¹³What is an Internet Exchange Point? - Cloudflare

3.4 Domain Name System (DNS)

Domain Name System (DNS), also called the Internet's phonebook, allows the conversion of domain names¹⁴. to IP addresses (Liu and Albitz, 2006). This system came as an answer to the lack of a universal way of connection and the unfriendliness of the usage from the consumers; remembering long strings of numbers for each search became quickly tricky. In 1983, Paul Mockapetris and his team created the Domain Name System to be first used by machines in 1986 which led to Internet usage as we know it (Bonastre and Veà, 2019). In the early years of its usage, DNSs were used to translate a domain name into its corresponding IP address simply. However, nowadays, with the geographic extension and many Internet users, a DNS has to get the information from the closest server to the consumer to provide the output in the shortest latency possible. Internet Corporation has coordinated the management of DNSs for Assigned Names and Numbers (ICANN) since its creation in 1998. The DNS industry functions on three levels supported by several firms : maintaining the hierarchy of databases, managing the leasing of SLDs in TLDs, and executing the query (Lehr *et al.*, 2021).

In the current market, some of the most used DNS servers are Cloudflare, Google Public DNS, Quad9, OpenDNS, Comodo Secure DNS, etc.¹⁵ This market is a crucial component of the Internet infrastructure but hard to grasp in its entire function. However, Lehr *et al.* (2021) estimates its value at \$8 billion considering critical problems of this industry such as market power, the importance of domain names and DNS abuse and security.

Another facet of this industry is the market of domain names and IP addresses. First, contrary to common belief, Top Level Domain Names aren't substitutes; a .com may have the same function as a .net but does not have the same perception from the consumers. Indeed, in a letter the United States Department of Commerce addressed to ICANN, they expressed their concerns regarding the market power of a single firm (VeriSign) in the registry of .com TLDs.¹⁶ This is more concerning as this TLD is the most used and preferred by firms; an exception is

¹⁴A Fully Qualified Domain Name is made up of four layers. To illustrate these layer, we will consider the domain name "www.ec.example.com". The first layer is the Root Zone, representing the dot ("."). The second layer is the Top Level Domain (TLD) corresponding to the .com part. The Second Level Domain (SLD) represents the allocated part that is given within the TLD to the SLD "example". Last, the Third Level Domain is a part of the subdomain which isn't always present, here the "ec" (the Economics Department of University Example)

¹⁵Best DNS servers of 2022

¹⁶Letter from the United States Department of Commerce to ICANN

to be made for .org which non-profit or governmental organizations highly choose. In addition, Mueller (2006) discusses the competition issue of VeriSign as a far-ahead leader in the market, which regulators must address. On the other hand, a behavioural economics model Farahmand (2017) attempts to predict domain name choices. Their results suggest that in the cases when .com is not the most preferred TLD, other ones like .tv or .cc stand out more when presented close to other .com.

Second, the market of IP addresses is particularly complex with the pending problem of the limited number of IPs and the growing need for them. There are two types of IP addresses: IPv4, the original ones and IPv6, the system created to answer to the nearing exhaustion of their predecessors. Edelman and Schwarz (2015) propose a dual viewpoint of the market of IPv4; on a theoretical side, they can be compared to the asset market, but, from an applied perspective, the pricing can be counterintuitive with an exogenous supply, stable addresses, growing demand. In 2011, Microsoft paid \$7.5 million to purchase 666,624 IPv4 addresses from Nortel (\$11.25 per address). Even though the option of IPv6 is available, the market of IPv4 is still consistent mainly as the transfer from one system to the other is quite costly. Nonetheless, Mueller (2008) suggest that the benefits outweigh the costs and this transition, perhaps wrongly radicalized, could be more helpful if extended in time.

3.5 Content Delivery Network

Defining Content Delivery Network (CDN) Lazar and Terrill (2001) is challenging. Still, in a nutshell, it could be described through one of its main purposes, a network of servers contributing to delivering data faster, more reliably and safely. With the evolution of the Internet and the ever-growing performance needs of the users and the firms, as well as the variety of content provided, since its creation in 1998 (Douglis and Kaashoek, 2001) the importance of CDN has increased as well as its complexity (Buyya *et al.*, 2008; Vakali and Pallis, 2003). According to Statista, from 2017 to 2022, the data volume going through DNSs has risen exponentially.¹⁷ Thus, great investments have been made in further developing the infrastructures as well as the services offered by CDN providers. The most used service is probably replication, allowing

¹⁷Data volume of global content delivery network internet traffic from 2017 to 2022 - Statista

one piece of data to be stored at more than one location, thus contributing to highly decreased latency. However, predicting CDN costs to decrease as its traffic arises, providers have started to come up with new products and services, for example : Content Service Network¹⁸ (CSN) and CDN software (Vakali and Pallis, 2003).

Stocker *et al.* (2017) propose a topology of CDNs separated into different architectures such as data center-based, highly distributed, peer-to-peer, hybrid, specialized, broker, licensed and federated. Wang *et al.* (2015) highlight data center-based CDNs as a crucial component as it is able to answer to the current market demand for content-delivery-as-a-service cloud models. The market is led by few main providers such as Cloudflare, Fastly, KeyCDN, StackPath, Akamai, BitTorrent, CacheFly. The CDN market was estimated at more than \$15 billion in 2021 and it is predicted to have a compound annual growth rate of 23%.¹⁹

4 Data centers

According to Gartner²⁰, a data center is the department of a firm that houses and maintains the Information Technology (IT) system and stores the firm's data. Even though this definition still holds, the current status of this industry has changed with the creation of the Cloud, a network of data centers. A data center is an ensemble of thousands of server racks in a building in a geographic location. A data center is made up of the facility itself, the IT infrastructure, electrical equipment, mechanical infrastructure and environment sensors. Its IT infrastructure consists of servers, communication equipment (switches, routers, patch panels, Internet Service Points) and a storage area. The well-functioning of these buildings depends on a group of factors : security, power and cooling, and workforce.

4.0.1 Location choice

Data center providers locate their servers in apartment blocks, deserts, and under the ocean, which doesn't seem to follow a pattern. Indeed, data center providers consider several key factors in the location selection process. First, these buildings are great energy consumers,

¹⁸CSNs will allow communication between Web servers, surrogate servers, and ISPs' proxies

¹⁹Content Delivery Network Market Size - Grand View Research

²⁰Data Center - Gartner

thus a reliable power infrastructure is essential. The previous factor goes hand in hand with the land, which will define the climate and environment. data centers must have their server rooms permanently cooled and keep the temperature stable. There are different ways to achieve it : through electric cooling (which can be very energy consuming and costly), air cooling or water cooling. The last option is considered to be one of the most energy-efficient as well as environmentally friendly. Hence, proximity to a water source can play a significant role. Third, providers tend to get as close to the user and network access points as possible, which can considerably reduce latency and network infrastructure (for example, cables). Even though these buildings are known to have very few employees, the proximity to a qualified workforce is taken into account. In addition, Greenstein and Fang (2020) test these variables and find that electricity prices do not affect the marginal entrant. Regarding climate and weather, one degree increase during the summer leads to a 4% decrease in the margins of new entrants. Furthermore, their result shows that population density is associated with a 1.059% increase in urban capacity. Recently, data regulation has put restrictions on the storage and computation location for different data types. For example, some very sensitive EU data can be stored and computed by non-EU Cloud providers, but the location has to be within the EU, which can explain the increasing number of US Cloud providers building data centers in Europe or collaborating with local data center providers. Hence, data location can become very costly considering privacy regulations as well as offering the needed security (Goldfarb and Treffer, 2018).

4.1 Distance

As mentioned above, distance is crucial for the data center market. Blum and Goldfarb (2006) show that physical distance negatively impacts online goods and services, which theoretically should be free of trade cost. Likewise, Couclelis (1998) argues that the digital age has not eradicated distance but demands adding nuances to the concepts of "near" and "far" to accommodate new hybrid spaces. Firms that acquire services from Cloud providers want to have access to their data and be able to serve their users in the best and fastest way. But, this gets more complicated once data centers deal with large firms with the user in many different locations worldwide. In such cases, firms will opt for a replication option choosing several locations to replicate and store

their data to get closer to the user. However, replications are a great solution to an unexpected incident. When a firm has a backup data center that can be deployed in hours and not days (time necessary to repair the incident), this option allows firms to avoid significant financial loss.²¹

4.2 Cloud and data center market description

The Cloud and data center market is an oligopoly with AWS, Microsoft Azure and Google Cloud as leading players (Goldfarb and Tucker, 2019) with a most popular pay-as-you-go model followed by reserving the services and storage space in advance. However, even though some prices might be publicly available, there is the commonly-known strategy of negotiating prices (mainly available for big firms).

For the remaining part, we will distinguish data center provider and Cloud provider to describe another layer of the market. The first ones detain the infrastructure containing all the servers. Cloud providers often rent servers or racks of servers according to their needs. This strategy is more financially advantageous as the Cloud does not need to deploy resources for the building's cooling, workforce, upkeep or security. They then add the software layer. As a result, the end-user might not be aware of the data center provider behind the Cloud provider they use. This strategy is referred to data center colocation.

4.3 Cloud adoption

IT investments are perceived differently by a young or large firm. For young firms, it can be risky and often requires resources that aren't available at an early stage (Jin and McElheran, 2017). On the other hand, Cloud service prices have significantly decreased, which led to an increase in cloud adoption. Since the Covid-10 health crises and the new challenges firms have faced in offering the right tools to their employees, creating hosting, security, and VPN needs, the industry has gotten to know a new expansion. By 2022, 94% of the firms use Cloud services. In 2020, Gartner recorded the value of the global Cloud computing market at \$313.8 billion²²

²¹This service for most of the Cloud providers is an option to be requested by the consumer. For instance, OVH Cloud clients that hadn't backed up their data during the 2021 incident had considerable losses. Recently, some Cloud providers have included it in the baseline package.

²²Gartner Says Four Trends Are Shaping the Future of Public Cloud

and predicts it will climb up to \$599.8 billion in 2023.²³

5 Conclusion

This paper tries to tackle the complex industry of the backbone network and data center. Broadband technologies have had the focus of research for the last decade. However, Cloud technologies, Domain Name Systems, Content Distribution Networks, Internet Exchange Points and connection technologies have passed under the radar. These technologies are expanding and changing rapidly, and economics research has just begun tackling the subject. This literature review is meant to be read as a short, simple manual of these architectures to encourage researchers. Even though the components and technologies of this industry are limitless, the main ones are owned by a dozen companies.

²³Gartner Forecasts Worldwide Public Cloud End-User Spending to Reach Nearly \$500 Billion in 2022

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