Data Center Geospatial Positioning

Research Proposal

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for

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Introduction

Much like we think the faucet in our homes is an infinite resource of running water summoned at our whim, we use our cellular phones, tablets, and computers without any thought to the infrastructure or its ontogeny that has made the resource possible (Hu, 2015). The backbone of the digital infrastructure is the modern data center. Unlike a public library, which represents the public's understanding of a centralized physical store of knowledge, data centers are an agora where most of today's information is stored. Invisible to the public but critical to first-world modern life. This project will examine the invisible world of data centers. First, this proposal will review evolutionary economics and how technology is important to a national economy. Next, the impact of technology on the U.S. economy will be discussed, and the impact of data centers on the U.S. economy will be analyzed. A review of data center location literature, data sources, and project methodologies will be presented. Finally, this proposal's candidate qualification will be presented, and any ethical considerations will be addressed.

Evolutionary Economics, Technology, and the National Economy

Adam Smith (1723-1790) had several remarkable insights about a state's economy in his 1776 publication, "An Inquiry into the Nature of Causes of the Wealth of Nations" (Smith, 1776). Smith saw the economy as an "invisible" chain of interconnecting mechanical parts (Warsh, 2006: 47). He saw that a state's economic machine could grow through the factors of scale and division of labor. However, Smith understood technology as exogenous to the market. Technology might incrementally improve the economy but only to make the economy more efficient (Warsh, 2006: 52). Efficiency leads to lower and lower costs and ultimately to the law of diminishing returns. Once some optimal level of productive capacity is reached, adding an additional factor of production will result in less output. However, John Start Mill (1806–1873) recognized that "[t]his law may … be suspended, or temporarily controlled, by whatever adds to the general power of mankind over nature; and especially by any extension of their knowledge ..." (Mill, 1848). Mill's "whatever" was technology. Karl Marx (1818-1883) had the insight that technology was endogenous and was the profit-making exploitive genius of the rising capitalist (bourgeoisie) class (Warsh, 2006: 74). However, it was not until Alfred Marshall (1842-1924) resolved the question of how market prices are determined (Warsh, 2006: 82) that the issues started to crystalize. Marshall discovered that falling costs of production had two sources. The first, "internal economies," or those like Smith had described and a second type called "external economies" (i.e., externalities) which resulted from general industry improvement, like those described by Mill and Marx (Warsh, 2006: 86). These externalities were "spillovers" and came from general endogenous technology innovations (Warsh, 2006: 88). Joseph Schumpeter (1883-1950) identified technological innovation as the force driving most economic progress. For Schumpeter, an economy grew because of the constant birth of new markets through innovation, causing the death of old markets. A process he called "creative destruction." Schumpeter saw that technology raises productivity and increases the quantity and quality of all the resources to which it is applied (Schumpeter, 1942). Schumpeter's theory was difficult to model, but eventually, Robert Solow (1924-) solved the modeling problem by allowing labor and capital to substitute for one another. Solow included a parameter in his model for the rate of technical change (Warsh, 2006: 144-145). However, because Solow's model considered innovation as arising exogenously, his model reached a point of equilibrium, and eventually, the economy stopped growing (Warsh, 2006: 201). It was not until Paul Romer (1955-) included the idea that innovation could arise endogenously through decisions made from within the system (Romer, 1983) that a model of an ever-expanding technology/innovation driven economy materialized (Warsh, 2006: 196). Eventually, it was found that the technical progress variable accounted for nearly 85% of economic growth (Warsh, 2006: 149). These advancements in economic thought led to the idea that the economy was not a machine but a growing evolving organism and that adjacent edge technological possibilities accumulate and multiply to grow the economy. Thorstein Veblen (1857 – 1929) labeled this concept "evolutionary economics" (Hodgson, 1998; Veblen, 1900). Progress does not run out; it accumulates (Brynjolfsson & McAffee, 2014: 75). Richard Nelson (1930-) and Sidney G. Winter (1935-) wrote in 1982 about the economy as an evolution of long-term progressive change from which new and quite different, futures will emerge from a set of dynamic processes (Atkinson, 2014: 12). In nuce, understanding the dynamic evolutionary economic processes as they relate the development of modern data centers will be the topic of this project. Governments have a role to play in promoting and transitioning markets, and countries with the strongest ability to organize production systems around the latest technology will have the best national production systems (Brynjolfsson & McAffee, 2014). Therefore, this project will also seek to identify national (Taylor, 2016; Baumol, 2007; Atkinson & Wu, 2017; Autor, 2015; Brynjolfsson & McAffee, 2014) and regional (Fritsch, 2013; Small Business Association, 2002) policies that might best promote technological advancement.

Information Technology and the U.S. Economy

Most of human history until the development of the efficient steam engine by James Watt in 1769 was boring. Human progress and population growth were relatively flat until the steam engine allowed man to replace muscle power with mechanical power. This first machine age allowed mass factories and transportation (Brynjolfsson & McAfee, 2014). According to Morris (2010), the steam engine resulted in "the biggest and fastest transformation in the entire history of the world." With the advent of computers and other digital devices, the world has entered a second machine age. According to Brynjolfsson & McAfee (2014), "computers and other digital advances are doing for mental power … what the steam engine … did for muscle power." Methodologies to evaluate the impact of the information sector on the U.S. economy are still being developed. However, Baumol (2002) estimates that "more than 60% of the labor force in the U.S. is engaged in activities in the "information sector" of the economy … far more than in manufacturing and agriculture, which, combined, constitute less than

20% of the total." (Baumol, 2002). A paper by James Bessen from Boston University found that computer use is increasing overall employment by 1.7% annually (Andes, 2016).

The digital economy employed over 7.8 million employees in 2020 for roughly $1.09 trillion in total compensation (Highfill & Surfield, 2022). According to the U.S. Bureau of Labor Statistics, employment in the computer and information technology occupations is projected to grow 13% from 2020 to 2030. Most additional jobs will be in cloud computing, collecting and storing big data, and information security (U.S. Bureau of Labor Statistics, 2022). Automation is also leading to wage growth by reducing prices which raises purchasing power (Atkinson & Wu, 2017; Andes, 2016). Additionally, analysis shows workers earn higher pay in the digital sector, and it appears that the digital sector has entered a virtuous circle (Mandel, 2017). Consumer satisfaction has been traditionally measured the lower price, greater quantity, or higher quality. However, these may no longer be adequate measures of consumer benefits from digitalization (e.g., Nakamura, Samuels, & Soloveichik, 2017; Byrne & Corrado, 2020; Turvey, 1997). Consumer welfare appears to be increasing as consumption moves from the physical to the digital world. (Brynjolfsson & McAfee, 2014).

Despite the challenges in measuring the value of the new digital economy, the U.S. Bureau of Economic Analysis estimates that the digital economy will represent roughly 10% of the overall U.S. Gross Domestic Product in real value in 2020 (Highfill & Surfield, 2022). See the table below:

Digital Economy to Total Gross Domestic Product (Real Value Added by Activity)
[Millions of chained (2012) dollars]
U.S. Bureau of Economic Analysis

	2012	2013	2014	2015	2016	2017	2018	2019	2020
Digital Economy	1,400,218	1,491,833	1,558,803	1,715,499	1,830,770	1,957,976	2,106,683	2,196,157	2,284,946
Total GDP	16,253,970	16,843,196	17,550,687	18,206,023	18,695,106	19,479,623	20,527,159	21,372,582	20,893,746
	8.6%	8.9%	8.9%	9.4%	9.8%	10.1%	10.3%	10.3%	10.9%

(Source: U.S. Bureau of Labor Statistics, 2022)

The most significant component of the digital economy (approximately 44% - 45%) is represented by the category "Priced Digital Services." See the table below:

Digital Economy to Total Gross Domestic Product (Real Value Added by Activi

[Millions of chained (2012) dollars]

U.S. Bureau of Economic Analysis

	2018	%	2019	%	2020	%
Digital Economy	2,106,683		2,196,157		2,284,946	
Infrastructure	751,418	36%	792,401	36%	844,842	37%
Hardware	285,035		286,330		306,921	
Software	463,782		502,749		534,428	
E-Commerce	416,341	20%	417,413	19%	441,750	19%
Business-to-Business E-Commerce	296,233		291,134		288,725	
Business-to-Consumer E-Commerce	121,082		127,743		156,336	
Priced Digital Services	940,775	45%	991,326	45%	1,000,448	44%
Telecommunications Services	481,641		490,260		482,131	
Cloud Services	74,597		93,936		108,286	
Internet and Data Services	124,754		136,159		139,666	
All Other Priced Digital Services	259,614		269,598		267,640	

(Source: U.S. Bureau of Labor Statistics, 2022)

The U.S. Bureau of Economic Analysis defines priced digital services as "services related to computing and communication that are performed for a fee charged to the consumer. Priced digital services products include cloud services, telecommunications services, internet and data services, and all other priced digital services." Real value-added average growth for priced digital services was 6.5% from 2012 to 2020 (Highfill & Surfield, 2022). These are the services that most closely align with data storage and delivery. In terms of 2020 current values, telecommunications services representing the delivery of data represented about 52% of the total priced digital services, while 48% represented what might be termed as data storage and maintenance (i.e., cloud services, internet and data services, and all other priced digital services. See the table below:

Digital Economy Gross Output by Activity, 2020
[Millions of dollars]
U.S. Bureau of Economic Analysis

	2020	% Total	% Subcategory
Digital Economy	3,305,894	100%	
Infrastructure	1,022,201	31%	100%
Hardware	394,437	12%	39%
Software	627,764	19%	61%
E-Commerce	831,490	25%	100%
Business-to-Business E-Commerce	581,298	18%	70%
Business-to-Consumer E-Commerce	250,192	8%	30%
Priced Digital Services	1,452,203	44%	100%
Telecommunications Services	754,551	23%	52%
Cloud Services	161,790	5%	11%
Internet and Data Services	202,486	6%	14%
All Other Priced Digital Services	333,376	10%	23%

(Source: U.S. Bureau of Labor Statistics, 2022)

The evolutionary economist suggests that the greatest driver of economic growth is the development and deployment of new technology. The driver of technology is the ability for new ideas to generate and rapidly come together in new formulations. There is an ineluctable drive for human beings to make this happen faster (Bowker, 2019), and digital information storage is accelerating that process. The advantage in today's digital economy is the power digital data platforms have in connecting disparate data and research and rapidly bringing that information together. Today the "digital economy" may only represent 10% of the U.S. GDP, but it plays an oversized role in driving economic growth. The exigency to understand how the data is being stored and how to anticipate the needs of the data storage industry has never been greater.

Data Center Industry

Evolution of the Data Center

Modern data centers can trace their beginnings to the large mainframe computer rooms of the 1940s. This type of housing was exemplified by the Electronic Numerical Integrator and Computer or the ENIAC, one of the earliest electronic data centers (Haigh, Priestley, Priestley & Rope, 2016). The ENIAC, developed during World War II, could perform 5,000 basic arithmetic operations per second. It utilized

18,000 electronic tubes, consumed 150 kilowatts of electrical power, and filled a room 30 × 50 feet. The "second-generation" computer was developed by IBM in 1959 and replaced electronic tubes with transistors (Campbell-Kelly, Aspray, Ensmenger & Yost,2019). These computer systems required complex cabling, organized in overhead housings or under raised floors. During the 1980s, the microcomputer became a technological possibility. These small personal computers (P.C.) proliferated in industrial and commercial applications. The P.C. was deployed throughout industries. As electronic information technology (I.T.) operations grew in complexity and importance, companies began coordinating I.T. resources. The client-server model was developed. This model linked more powerful larger P.C.s, called servers, with the less powerful and less expensive smaller P.C.s, called clients. As the number of server installations grew, they became centralized into rooms, and the use of the term "data center" entered the I.T. parlance (Bartels, 2011). As these rooms grew in complexity, they began moving into separate buildings. P.C. became affordable for personal ownership and began being installed within households. All P.C.s began to connect through telecommunication advances to other computers worldwide, creating the internet. The internet became a dominant feature of the digital world, and during the late 1990s, the dot-com boom accelerated the need for company websites (Harvey, 2021). Suddenly every organization needed fast connectivity, continuous computer operations, and an internet website (Harvey, 2021). For many companies creating the necessary computer, infrastructure was not an option. The solution was to share infrastructure (Bowman, 2008). The economies of shared computing services resulted in the creation of data center operational companies. These companies built very large computer facilities that connected smaller companies to the internet (Holusha, 2020) and eventually created the data center industry that linked all computers to the "cloud." A brief note on the "cloud." The term "cloud" is a bit confusing. However, "the cloud" is not overly complex to understand at its core. The cloud is a model – not a thing - for delivering infrastructure, digital storage, and application resources on-demand (Lowe, Davis & Green, 2016). Understanding the model requires understanding the very important concept of layers in computer science. Computer scientists typically divide technical apparatus into abstract layers. Each layer moves progressively from the most physical or least abstract to the least physical or most abstract. The least abstract or bottom layer is the physical components (e.g., cables, servers, data centers, etc.). The next higher layer is Internet and transmission protocols that allow communication between physical devices. Toward the upper layer is the application software (Hu, 2015). Layers within the cloud can be reorganized, moved, reconnected, and modified. Sometimes the modification of one layer can impact other layers but often not. The term "the cloud" is often used inappropriately but interchangeably with anything that involves delivering hosted services over the internet but is better thought of as clusters of physical connections and services that are not location dependent (Siemon Data Center E-Books, n.d.).

Data Centers

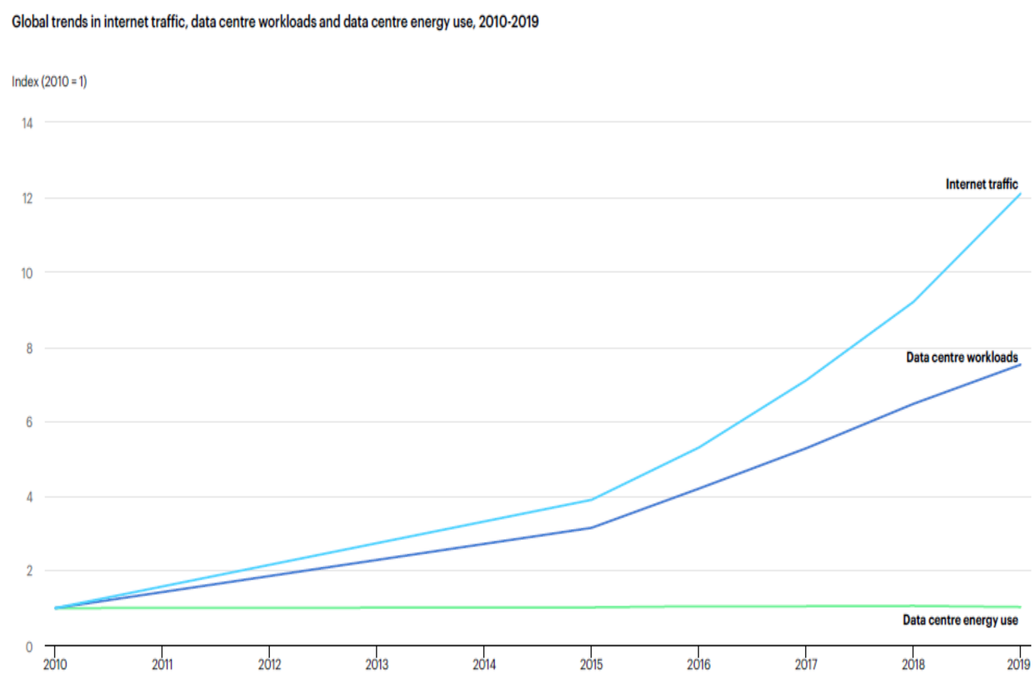
Data centers exist at the boundary between digital data's virtual world and buildings and servers' physical world. Data centers are the veritable quintessential dividing line between the inside and outside worlds of the cloud. Yet there is nothing special about a data center. Outside, you see no science fiction-looking blinking lights or spinning globes. Normally they are nondescript and windowless buildings. Their architecture fits comfortably among postindustrial warehouses or an office park. (Hu, 2015). The Telecommunications Industry Association (TIA) defines a Data Center as "a building or portion of a building whose primary purpose is to house a computer room and its support areas" (Ayomaya, n.d.).

Typically, datacenters provide space, security, power, telephone switches, routers, and other large-scale network equipment (Koomey, 2008). Data centers come in three flavors: Enterprise Data Centers, Managed Hosting Platform, and Colocation Data Centers (Cole, 2012). Enterprise data centers are specific single-purpose computer center assets owned and operated by an individual owner. They are the primary data center that houses a company's mainframe computer or its growing server network. These data centers offer businesses optimal control over their I.T. operations and equipment (Cole, 2012). Managed Hosting Platform, also known as shared infrastructure, data centers are multi-tenant single-purpose centers housing infrastructure improvements such as computer-grade power supply, emergency power service generators, air conditioners, security systems, and maintenance staffing. Tenants take largely unimproved space and install their own computer equipment (Siemon Data Center E-Books, n.d.). The tenant rents the infrastructure it needs instead of investing in it outright (Cole, 2012). Collocation data centers have improvements like a shared managed hosting platform but also include cabinets, computer servers, and telecommunication equipment. Services are sold by the cabinet and computer server (Bowman, 2008). Collocation facilities are typically divided into cages, cabinet space, or in some cases, subdivided cabinets. Collocation data centers are becoming more attractive for companies (Siemon Data Center E-Books, n.d.).

A data center can be like a miniature city of computer servers, data storage devices, networking equipment, infrastructure, technicians, and management teams (Hu, 2015). Computer servers are the workhorse computers that process and move data (Shehabi, Smith, Masanet, & Koomey, 2018). Data storage devices are divided between hard disk drives (HDD) and solid-state drives (SSD) and provide the data center's data storage technologies. Networking equipment includes the cables and switches necessary to transmit electronic signals across internal data center networks (Shehabi, Smith, Masanet, & Koomey, 2018). Finally, infrastructure consists of such items as cooling systems, lighting, power supplies (Shehabi, Smith, Masanet, & Koomey, 2018), and emergency response equipment. In addition to staffing teams, data centers often deploy Data Center Infrastructure Management (DCIM) software to assist with operational management. Gartner, a management consulting firm, defines DCIM as "tools that monitor, measure, manage and control data center use and energy consumption of all IT-related equipment …, and facilities infrastructure components ..." (Cole, 2012; Gartner, 2019).

Data Center Growth

The world is creating unimaginable amounts of new data. The World Economic Forum estimates that globally, by 2025, 463 exabytes of data will be created each day (Sunil, 2021). Dave Mosley, CEO of Seagate Technology, said, "More data is created per hour now than in an entire year just two decades ago. Data is human potential" (IDC, 2019). This rapid increase in data is having a profound impact on internet traffic. As indicated in the graph below, global internet traffic doubled between 2016 and 2019 and is projected to double again by 2022.



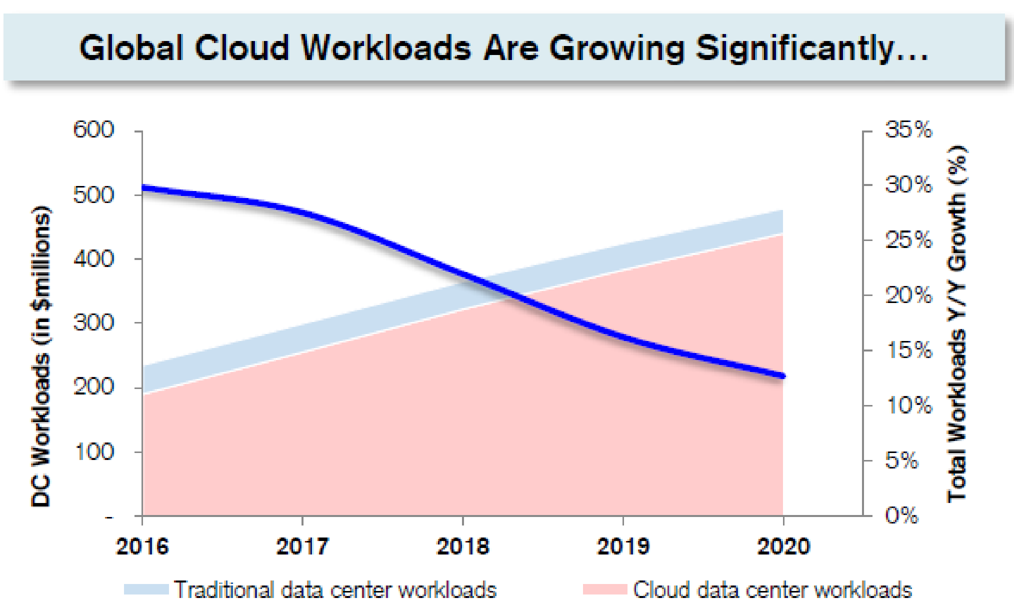
(Source: IEA, 2021)

Today, more traffic is occurring from wireless and mobile devices, which is expected to make up more than 70% of total traffic by 2022, up from around 50% in 2019. In addition, there is a growing demand for streaming video and gaming. Between 2019 and 2022, traffic from internet video (e.g., video streaming, video conferencing) is projected to more than double, while online gaming is projected to quadruple. Social networking is also a major driver. Emerging digital technologies such as machine learning, blockchain, 5G, and virtual reality are also poised to raise the demand for data services (IEA, 2021). However, only 2% of the 2020s newly created digital data was saved (Statista, 2021a). Additionally, a survey of 1,500 information technology professionals established that only 32% of the data available to enterprises was being leveraged. (IDC, 2019). This situation creates an exigency for additional storage. Currently, most of the storage demand is being fulfilled by cloud providers. See the table below:

	Amount (terabytes)	Percent
Cloud (public, private, industry, third-party)	422	42%
Internally managed data centers	297	30%
Edge & remote locations	193	19%
Other locations	89	9%
	1,001	100%

(Source: Statista, 2020a)

However, to fulfill demand, storage capacity is forecast to grow at a compound annual growth rate of 19.2%, between 2020 and 2025 (Statista, 2021a). The new capacity is projected to occur in cloud-based data centers. See the graph below:

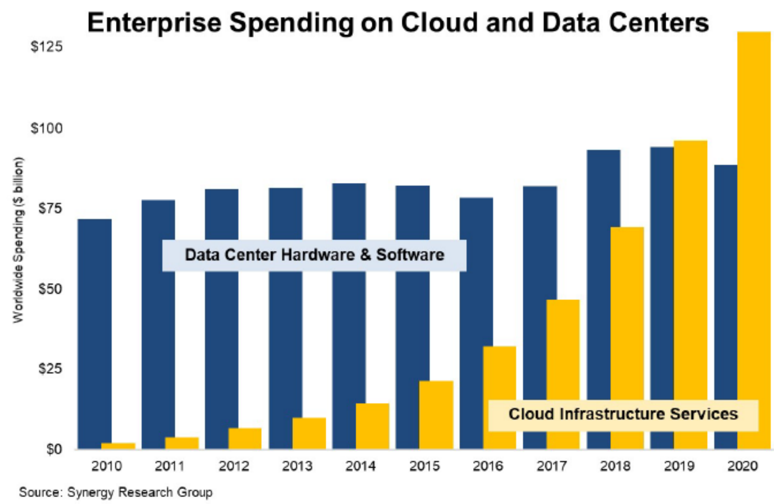


(Source: Badri, 2017)

Synergy estimates that 60% of server sales are now going to cloud provider data centers and not those of enterprises. (Ascierto & Lawrence, 2020) and Gartner predicts that by 2025, 80% of enterprises will have migrated entirely away from on-premises enterprise data centers and into hosting or colocation data centers. (Preimesberger, 2018; Gartner, 2019). This trend is supported by a recent survey of 3,400 information technology professionals worldwide, with 86% seeing movement into the cloud environment as the ideal operating model (VansonBourne , 2020).

Enterprise Spending Data Centers

The overall spending on global information technology came to $3.87 trillion in 2020 and is expected to increase by approximately 9.5% in 2021 (Statista, 2021b). In 2020, driven by demand for modern networking, storage, and data solutions, enterprise spending on cloud infrastructure services amounted to almost $130 billion, a growth of more than 34% compared to the previous year (Statista, 2021b). The worldwide equipment market for data centers was $38 million in 2015 and is expected to grow to $71 million by 2020 (Statista, 2016a). Global spending on data center hardware and software in 2015 was $118 billion and is estimated to grow to $152.5 billion in 2019 (Statista, 2020b). Arizton, a market research firm, valued the 2020 U.S. data center market size at $82 billion and expects it to cross $96 billion by 2026, a CAGR of 3% (Arixton, 2021). As indicated above, in regards to a transition from data being stored in cloud-based operations rather than enterprise operations, the spending on cloud-based computing is also transitioning to cloud-based operations (Synergy Research Group, 2021). See the chart below:



(Source: Synergy Research Group, 2021

Data Center Market

The global data center service market is fragmented, and competition is high (Mordor Intelligence, n.d.). According to Statista (Statista, 2020c), below are the leading data center providers by the number of applications hosted worldwide in 2019:

Company	Number of Applications Hosted (2019)	Company	Number of Applications Hosted (2019)
CenturyLink	139.5	Claranet	30.5
Equinix	132.5	ChinaNetCenter	21.5
NTT Communications	97.5	Sungard	17.5
Data Foundry	71.5	QTS	13.0
BT	68.0	Zen Internet	6.5
Cyxtera	63.5	CyrusOne	6.0
ATT	57.0	Digital Realty Trust	3.5
China Unicom	53.0	21Vianet	3.5
Tierpoint	42.0	DataBank	2.0
Telehouse (KDDI)	41.0	Netcetera	2.5
China Telecom	40.0		

(Source: Statista, 2020c)

No single company or group has taken control of the market, but it appears that the market may be encouraging consolidation by rewarding larger companies with higher share prices (Badri, 2017). In

2019, global revenue from the colocation data center market was about $31 billion. Industry revenues are expected to increase to over $58 billion by 2025 (Statista, 2021c). Within the U.S., the demand for data center capacity by industry in 2020 is mostly in the cloud, technology, and banking/financial services industries. Healthcare and energy represent the second highest industry consumers, followed by retail/e-commerce, telecommunications, and entertainment/media (Statista, 2021a).

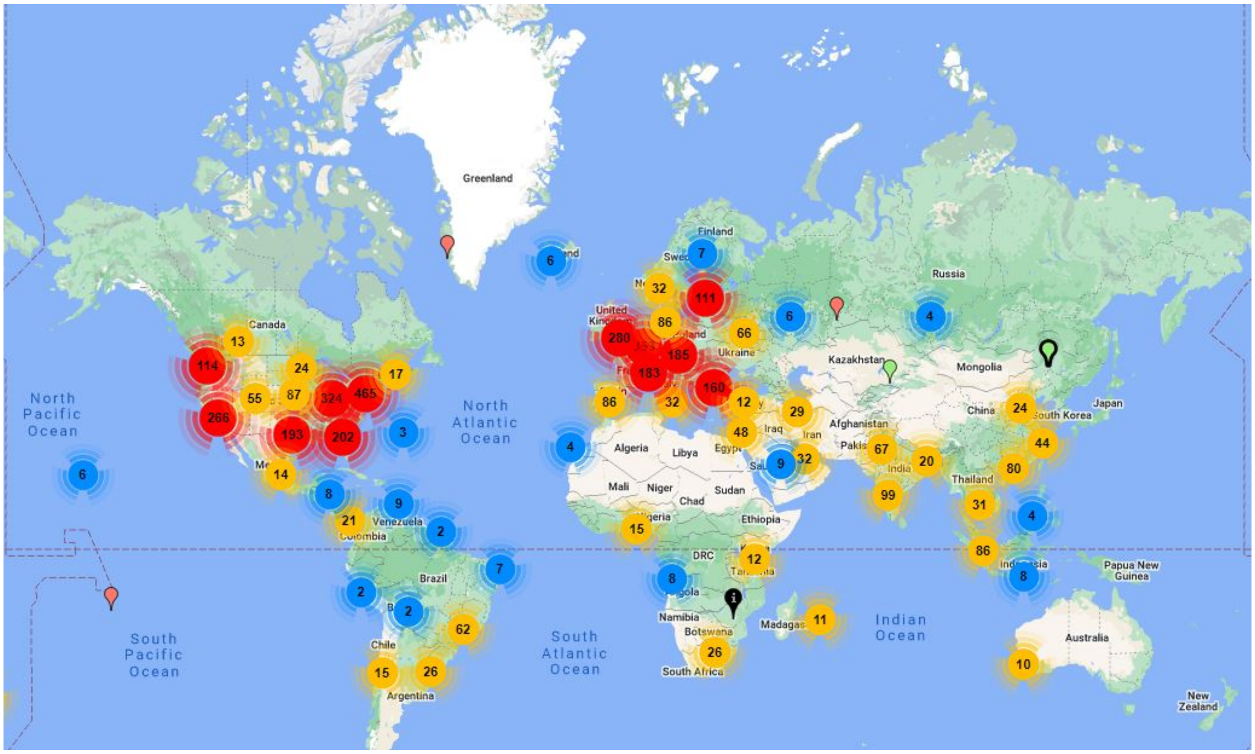
Data Center Locations

If all the data centers constituted a country of their own, Greenpeace calculated, it would be the fifth most power-hungry country in the world (Hu, 2015). They are "… a critical backbone of the worldwide … infrastructure" (Buyya et al., 2009). As of 2021, Statista (2021d) reports that there are 6,040 data centers worldwide:

Country	Count	Percentage
U.S.	2,670	44%
UK	452	7%
Germany	443	7%
China	416	7%
Netherlands	275	5%
Australia	272	5%
Canada	269	4%
France	248	4%
Japan	205	3%
Russia	145	2%
Mexico	141	2%
Brazil	133	2%
Italy	125	2%
India	123	2%
Spain	123	2%
	6,040	100%

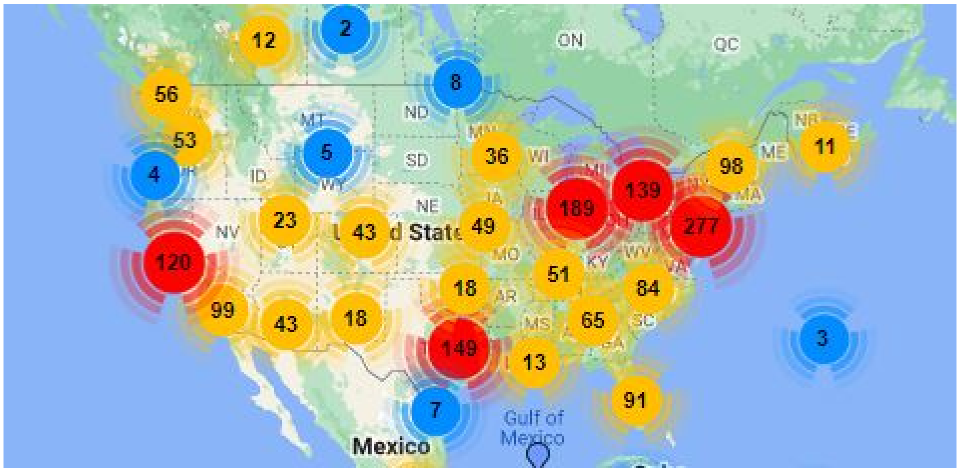
(Source: Statista, 2021d)

While data centers are located around the globe, they are concentrated in North America and Europe:



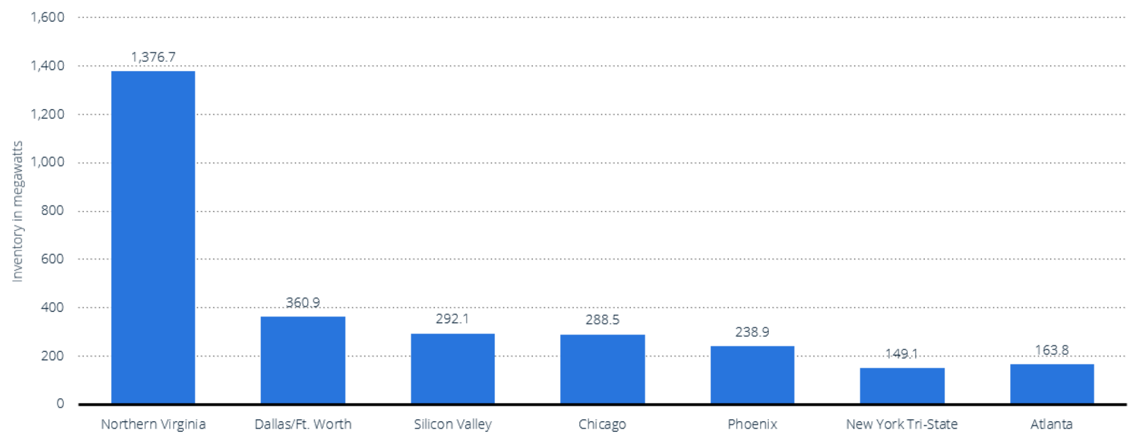
(Source: Datacentermap.com, 2022)

Within North America, most data centers are concentrated in certain geographic areas within the U.S.:



(Source: Datacentermap.com, 2022)

Within the U.S., most of the data centers, in terms of megawatts of power, are located in Northern Virginia, followed by Dallas/Ft. Worth and Silicon Valley (Statista, 2021d):



(Source: Statista, 2021d)

Literature Review

Introduction

Due to the modest cost of optical fiber networks, data centers might be located almost anywhere they are not confined to major urban areas (Hu, 2015). Despite this, a literature review found that few studies focused on describing where data centers are located and, more specifically, on what factors might drive them to those locations. Rather, most studies have been proscriptive, describing where data centers should be located to ensure the lowest cost and highest benefit (Covas, Silva, & Dias, 2013; Muro & Liu, 2021)

Proscriptive Models

The prescriptive literature general proposes various decision-making and factor balancing methods for data center location selection. Some approaches focus on Euclidean distances or other distance modeling (e.g., Eiselt and Marianov, 2011; Covas, Silva, & Dias, 2013). However, as noted above, distances might not be the most important factor in data center site selection. Using analytical methods, other models have sought to optimize various factors (e.g., energy, land, connection costs, physical security, economic and political risk, etc.). For example, Chang et al. (2007) solved a capacitated p-median problem to select the optimal location of U.S. army data centers. Ouni et al. (2015) used a mixed integer linear programming (MILP) model to select the data center's optimal location from five Quebec areas. Goiri et al. (2011) assessed potential data center locations in the U.S. using a nonlinear cost optimization model that minimizes the costs of network latency, consistency delay, and availability constraints. Abbasov et al. (2009) suggested a linear integer programming model. Their model determines optimal locations based on possible natural, political, and economic risks. Larumbe and Sanso (2012) proposed a convex integer programming model. The objective function in the proposed model would minimize the average network delay, subject to system and budget constraints. Finally, Klinkowski et al. (2013) focused on the optimization algorithms that minimize the required spectrum in the location selection problem of the data center. Muro & Liu (2021) suggests that analytical modeling may leave out some location criteria, especially the qualitative ones. Additionally, they suggest that mathematical models may have limitations due to the increasing complexity. Addressing this concern, other approaches that are not strictly mathematical have been proposed. For example, Yang and Ye (2011) used a Delphi method to select a data center location in China (Muro & Liu, 2021). Covas et al. (2010) applied an Elimination and Choice Expressing Reality III in a group decision-making environment for locating data centers in Portugal. Daim et al. (2013) proposed a hierarchical decision model (HDM) to select the best location for a data center. Covas, Silva, & Dias, 2013, suggest a multicriteria decision analysis (MCDA) approach. MCDA approaches (see Belton & Stewart,2002; Bouyssou et al.,2006; Roy,1991; Figueira et al.,2005) acknowledge the existence of multiple dimensions for evaluating alternatives without attempting to reduce them to a monetary scale. No prescriptive model has emerged as dominant. However, there has been a murmuration around certain optimization factors. For a listing of the various factor categories, criteria, and sub-criteria, see Appendix (I).

Descriptive Models

As noted, few models attempt to understand where data centers are being located instead of where they should be. However, there are components of a model that might help explain data center locations. For example, Steven Johnson (1968 -) said that an important component of innovation is the likelihood that different ideas from different disciplines bang against each other. During the 1970s, 80% of significant innovation came from large firms acting alone. However, after that period, 67% of new significant innovations were developed by the private sector in partnership with government agencies, laboratories, and universities (Block & Keller, 2009; Kirchhoff, Armington, Hasan & Newbert, 2002). According to Block and Keller (2009), the consensus is that successful technological innovation requires multidisciplinary activities that bring together different ideas and types of expertise (Block & Keller, 2009). Additionally, for many of today's companies, the most consequential innovation-promoting investment may be fresh from university engineering, and science program hires (Hicks, 2001). Time-to-market pressures and first-mover advantage might also influence (Hicks, 2001; Storper & Venables, 2004). Hu, 2015 noted that some data centers are repurposing old Cold War spaces. For example, the Pionen nuclear bunker underneath Stockholm to house WikiLeaks. Thus, latency might be important (Hu, 2015). Combining these theoretical elements, we should expect to see data centers forming, at least initially, in urban areas. Urban areas allow for the greatest opportunity for new idea generation as they typically have scientific laboratories, research facilities, and universities nearby. Urban areas might also have the latent infrastructure more readily available, allowing for the quickest time-to-market. Once data centers begin to appear. However, a theory known as "Data Gravity" might drive additional data center development at nearby locations. Data Gravity hypotheses that as data grows at a specific location, it is inevitable that additional services will be attracted to that location due to latency and throughput requirements. In effect, growing the mass of data at the original location. This theory is comparable to the well-known economic theory of agglomeration (Fujita & Thisse, 1996; McCann, 1995; McCann & Oort, 2019; Mulligan, 1984; Storper & Venables, 2004). Data gravity suggests that data location is central to most decisions made by information technology leaders when it comes to the geographic alignment of a data center (Sunil, 2021; Digital Realty, 2020). This theory aligns with the idea that at the earliest stages of technological development there is often spatial concentration near the site of the key innovations, given their dependence on localized human networks exchanging "sticky information." However, this same "sticky information" theory suggests that at later phases of adoption and commercialization, the potential for dispersion exists as earlier-stage innovation gives way to more "codified" adoption (Storper & Venables, 2004).

Contribution to Literature

Theorists say it does not matter where the digital-physical layer resides so long as it meets the technical requirements for connectivity. So, we need not concern ourselves with where the digital-physical layer is situated in ontological space. Such a position masks the slow movement of the physical processes that power data centers. The virtual digital world moves quickly, but the physical world changes much slower. We cannot ignore the workers that must unload equipment at the docks, installers that install that equipment, local suppliers, or universities that produce the technicians, managers, and scientists working at the center (Hu, 2015; Parks, 2007). We cannot ignore the social, economic, and environmental impacts a data center might produce (Cook, 2012). Technology adoption has massively altered the economic landscape, upping the urgency for our understanding of that economic development. (Storper & Venables, 2004). The fact is that physical data centers are a layer of technology that is a shared social and economic enterprise worthy of analysis. Understanding how the infrastructure developed is developing, and the forces that define it will bring a new appreciation to our modern life and perhaps provide a bit more control over the process. This project seeks to fill a gap in the research literature by focusing on the data center industry's evolutionary economic, social, and political aspects through an analysis of data center location development and dispersion. By understanding this development, nations and regions can better prepare themselves for the data center industry's continued development.

Data Source

The Dallas-Fort Worth Federal Statistical Research Data Center (RDC) is a repository of U.S. Census Bureau information. The RDC has the necessary North American Industry Classification System (NAICS) codes (see Appendix II) for related NAICS codes) at the zip-code level sufficient to conduct a summary statistical analysis. The RDC data also has the benefit of time series information.

Methodology

Research Question

This project proposes to answer the following research question:

What factors explain the U.S.' geographic distribution of Data Centers?

In examining this research question, the project will examine the unequal distribution of data centers within the U.S. and seek to explain how and why that distribution has developed. The project will also evaluate what evolutionary economic policies might be developed to enhance economic development in this area.

Model Designs

The study's objective will be to determine and measure the relationship between a data center location and independent variables. The unit of analysis will be the individual data center, and the primary dependent variable will be the geographic location of individual data center operations within the U.S. A data center's U.S. zip code will be the primary unit of measurement. Explanatory and independent variables will include economic (e.g., regional GDP, material costs, energy costs, technology expenditures, land and construction costs, local incentives, etc.), latencies (bandwidth, cloud storage, internet of things, distances to road/rail/airports, etc.), environmental (e.g., population, attractiveness, temperature, noise, air pollution, water, etc.), and social factors (e.g., life quality, legal, waste management policies, etc.).

Two modeling methods are proposed: first, a spatial clustering model and, second, a multiple linear regression model. Industry clusters consist of large and small firms within a single industry. Economic theory suggests that these agglomerations benefit from synergies of association relating to shared labor, information, technology, and infrastructure. In addition, the availability of transportation, utilities, technology training facilities, and research laboratories can also support the generation of an industry cluster (see Deeb & Niepel, 2008).

A regression model attempts to identify those aspects, namely, independent variables, of a defined geographic area (e.g., Metropolitan Statistical Area) that potentially contribute to the placement of a given industry, namely, the dependent variable. Such an optimization linear regression model can be formulated as follows:

$$Data\ Center_{(zip\ code)} = \beta_0 + \beta_1(Economic) + \beta_2(Latencies) + \beta_3(Environmental) + \beta_4(Social) + \epsilon$$

Regression models can be developed under several strategies (see Abbasov, Aliev, & Kerimova, 2009; Sutaria & Hicks, 2004). Ultimately data availability will suggest the most appropriate regression strategy.

Candidate Qualifications

I hold a Master of Economics (2019) and a Master of International Political Economy (2021) degree from the University of Texas at Dallas. I studied innovation economics with Dr. Hicks (Fall 2020), Regression and Multivariate Analysis with Dr. Brandt (Spring 2020), Time Series Analysis Dr. Clarke (Spring 2019), Applied Econometrics Dr. Grover (Spring 2017), Machine Learning for Socio-Economic and Georeferenced Data Dr. Tiefelsdorf (Spring 2022), and Geographic Information Systems Fundamentals Dr. Chun (Fall 2021). In addition, I hold a Master of Business Administration with Distinction from California State University, Northridge (1993), a Juris Doctorate from Loyola Law School California (1999), and a Bachelor of Science in Business Administration Accountancy with Great Distinction from California State University Long Beach (1984). I feel confident that I can complete the project with the computer programming, analytic, writing, and research skills that I have developed, most recently at UTD, and from my overall educational and professional experience.

Ethical Considerations and Institutional Review Board Approval

This project is merely analytical and therefore presents little to no ethical concerns. As this project will not use human subjects, a review by the Institutional Review Board is unwarranted.

Appendix I

Factors used in analytical site selection models:

Category	Criteria	Sub-criteria	Refrences
Commercialization	Companies providing solutions	All	22
Commercialization	Job postings requiring skills	All	22
Commercialization	Job probiles with skills	All	22
Economic	Application use cases	All	15
Economic	Cloud usage	All	15
Economic	Competitor positions	All	15
Economic	Data creation rates	All	15
Economic	Economic risks	Anailability of preferred support vendors	15
Economic	Economic risks	Availability of qualified support vendors	1, 6
Economic	Economic risks	Dependence on the national economy	1, 3
Economic	Economic risks	Effective communication between investors and the market	1, 3, 15
Economic	Economic risks	Military regional security (active defensive, nonactive defensive, frontier threats)	1, 3, 4, 6
Economic	Economic risks	Natural and ecological risks (electromagnetic radiation)	1, 4
Economic	Economic risks	Natural and ecological risks (nuclear)	16
Economic	Economic risks	Natural and ecological risks (other)	1, 3, 6
Economic	Economic risks	Natural and ecological risks (Other, storms, floods, landslides)	1, 3
Economic	Economic risks	Natural and ecological risks (pollution)	1, 10
Economic	Economic risks	Natural and ecological risks (Seismic)	1, 3, 6, 7, 13
Economic	Economic risks	Physical security	1, 4, 14
Economic	Electrci grid connection cost	All	1, 6, 7, 7
Economic	End point user devices	All	15
Economic	GDP	All	15
Economic	Growth rates	All	15
Economic	Investment costs	All	1, 6, 9, 15
Economic	IT spend	All	15
Economic	Land acquisition and construction cost	All	1, 6, 7, 8, 7
Economic	Latency rate	Access	15
Economic	Latency rate	Application type	15
Economic	Latency rate	Location	15
Economic	Latency rate	New construction applications	21
Economic	Latency rate	User type	15
Economic	Local Incentives	Access to subsidies	1, 3, 7
Economic	Local Incentives	Competative prices	1, 3, 7
Economic	Local Incentives	Ease of licensing	1, 3, 7, 7
Economic	Local Incentives	Free land	1, 3, 7
Economic	Local Incentives	Tax reduction	1, 3, 7
Economic	Natural gas grid conneciton costs	All	1, 6
Economic	Network communications connection costs and fees	All	1, 2, 6, 7, 7, 7, 7, 14, 15
Economic	Operational costs	All	1, 6, 8, 7, 14
Economic	Operational costs	Climate conditions costs (Humidity, Temperature)	1, 5, 6, 7, 14
Economic	Operational costs	Energy costs (including energy savings strategies, renewables)	1, 6, 14
Economic	Operational costs	Human resources cost	1, 4, 6, 7
Economic	Operational costs	Land price	21
Economic	Operational costs	Taxes	1, 3, 4, 6, 7, 11
Economic	Synchronization cost (connection between DCs)	All	1, 6
Environmental	Energy savings	All	1, 4, 6, 11, 12, 13
Environmental	Energy savings	Heat waste from Data Center reusability	1, 6
Environmental	Energy savings	Potential for free cooling by water	1, 7, 8
Environmental	Energy savings	Potential for free coooling by air	1, 6, 8
Environmental	Energy savings	Renewable energy sources	1, 6
Environmental	Infrastructure	Cloud storage	11
Environmental	Infrastructure	Average bandwidth	15
Environmental	Infrastructure	Internet of Things	11
Environmental	Infrastructure	Technographics	15
Environmental	Interference with protected areas	All	1, 7
Environmental	Local pollution	Air polution	1, 4, 6
Environmental	Local pollution	All	1, 3, 4, 6, 10
Environmental	Local pollution	Noise	1, 4
Environmental	Local pollution	Residues	1, 3, 4, 6, 10
Environmental	Local pollution	Temperature	1, 5, 6, 7
Environmental	Population	All	15
Environmental	Population	Employees	15
Research	Academic paper at top conferences	All	22
Research	Fed R&D contract spending to private firms	All	22
Research	Fed R&D grants to universities	All	22
Research	Patents	All	22
Social	Attractive to customer (distance to data center)	Distance to airports	1, 6
Social	Attractive to customer (distance to data center)	Distance to main road	1, 6
Social	Attractive to customer (distance to data center)	Distance to rail stations	1, 6
Social	Availability of skilled labor	All	1, 6, 7, 8, 15
Social	High-tech talent	All	1, 4
Social	Information security	All	1, 4
Social	Level of expansion of society	All	1, 4, 6
Social	Life quality (attractiveness to employees)	Avaiability of public transportation (Rail, roads, airport)	1, 7, 15, 20
Social	Life quality (attractiveness to employees)	Life cost (taxation)	1, 7, 20
Social	Life quality (attractiveness to employees)	Life seccurity (crime aainst property / person), police, firemen)	1, 4, 7, 7, 17, 18, 19, 20
Social	Political risks	Change in policies & laws	1, 3, 6
Social	Political risks	Compliance requirements (e.g. UN 2030 Agenda, DoD NIST 800-171)	12
Social	Political risks	Existence of restrictive laws	1, 4
Social	Political risks	Gov. failure to comploy with obligations	1, 10
Social	Political risks	Green Metrics	14
Social	Political risks	Inefficient / imcomplete laws	1, 3
Social	Political risks	Weakness of international relations	1, 5

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Appendix II

Digital Economy Activities and Detailed Industries

Digital economy activities	NAICS industries	NAICS description
Infrastructure		
Hardware	333242	Semiconductor machinery manufacturing
	333293	Printing machinery and equipment
	333990	Other general-purpose machinery manufacturing, repair work
	334110	Computer and peripheral equipment manufacturing
	334200	Communications equipment manufacturing
	334310	Audio and video equipment manufacturing
	334410	Semiconductor and other electronic component manufacturing
	334610	Manufacturing and reproducing magnetic and optical media
	335920	Communication and energy wire and cable manufacturing
	335999	All other miscellaneous electrical equipment and component manufacturing
Software	511210	Software publishers
	541511	Custom computer programming services
E-commerce		
Business-to-consumer (B2C)	441000	Motor vehicle and parts dealers
	442000	Furniture and home furnishings stores
	443000	Electronics and appliance stores
	444000	Building material and garden equipment and supplies dealers
	445000	Food and beverage stores
	446000	Health and personal care stores
	447000	Gasoline stations
	448000	Clothing and clothing accessories stores
	451000	Sporting goods, hobby, book, and music stores
	452000	General merchandise stores
	453000	Miscellaneous store retailers
	454000	Nonstore retailers
Business-to-business (B2B)	423000	Merchant wholesalers, durable goods
	424000	Merchant wholesalers, nondurable goods
	425110	Business to business electronic markets

Digital economy activities	NAICS industries	NAICS description
Priced digital services		
Cloud services	511210	Software publishers
	518210	Data processing, hosting, and related services
	519130	Internet publishing and broadcasting and web search portals
	541400	Specialized design services
	541510	Computer systems design and related services
Telecommunications services	512110	Motion picture and video production
	515120	Television broadcasting
	515210	Cable and other subscription programming
	517110	Wired telecommunications carriers
	517120	Wireless telecommunications carriers (except satellite)
	517410	Satellite telecommunications
	517910	Other telecommunications
Internet and data services	512110	Motion picture and video production
	517110	Wired telecommunications carriers
	517919	All other telecommunications
	518210	Data processing, hosting, and related services
	519110	News syndicates
	519130	Internet publishing and broadcasting and web search portals
All other priced digital services	541512	Computer systems design services
	541513	Computer facilities management services
	541519	Other computer related services
	611420	Computer training
	811211	Consumer electronics repair and maintenance
	811212	Computer and office machine repair and maintenance
	811213	Communication equipment repair and maintenance

Source: Highfill, T. & Surfield, C. (May 2022), New and Revised Statistics of the U.S. Digital Economy, 2005–2020. Bureau of Economic Analysis.
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