

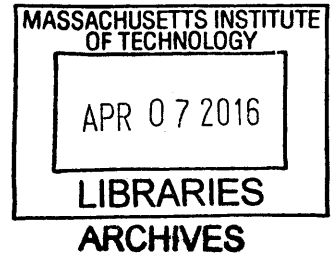
**Identifying Data Center Supply and Demand**

by

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**B.A., History, 2006**

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**Submitted to the Program in Real Estate Development in Conjunction with the Center for Real Estate in Partial Fulfillment of the Requirements for the Degree of Master of Science in Real Estate Development**

at the

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## **ABSTRACT**

This thesis documents new methods for gauging supply and demand of data center capacity and addresses issues surrounding potential threats to data center demand. This document is divided between a primer on the composition and engineering of a current data center, discussion of issues surrounding data center demand, Moore's Law and cloud computing, and then transitions to presentation of research on data center demand and supply.

**Thesis Supervisor: Dr. Andrea Chegut  
Postdoctoral Research Associate, Center for Real Estate**

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## Chapter 1: Introduction

For all its omnipresence, the Internet has an extremely valuable physical footprint. It is hard to overstate the size, growth or importance of the information networks collectively known as 'the Internet'. Current estimates project 23% compound annual growth for all global IP traffic between 2014 and 2019, with many more superlatives and astounding statistics to show that the Internet is growing at an astounding clip. ("Cisco Visual Networking Index: Forecast and Methodology, 2014–2019" 2015) Within the past few decades a new real estate product type, the data center, has arisen in stride with the growth of Internet adoption and traffic. Data centers are the facilities in which the world's data is stored, calculated and shipped. These facilities have been important components of economic and technological advancements in the recent past and are increasingly important to economic development and the real estate industry.

The Internet's growth and development is rearranging the world, making this information exchange and storage system the most important development in global commerce and communication so far. Digital communication has grown dramatically over the past decades and worldwide adoption across all economic tiers continues to grow at astounding rates ("Measuring the Information Society Report" 2015).

Since the 2008 announcement that 'the data center is the computer' (D. A. Patterson 2008), data centers have displaced the desktop computer as the locus of the world's heavy-duty computing, information storage and routing. It is now the case that data centers don't simply host the Internet, they *are* the Internet. As such, this new product type offers tremendous opportunity for investment, as these assets' performance can mirror the astounding growth of the Internet sector whilst offering the tangibility and security of a real estate investment.

As real estate, these facilities are valuable but not very well understood. Traditional real estate axioms regarding location, constructability, serviceability and leasing lose relevance against a new product type whose tenants' primary concerns surround uptime, latency and efficiency. Key variables in determining the value of a data center include locational attributes, infrastructure, bandwidth characteristics, tenant mix, and power density within the facility.

As such, potential players in the data center real estate market must develop a new set of metrics for evaluating industrial computing facilities. These areas are as follows:

### **Translation of data center typology to real estate typology**

The remarkable growth of this new real estate product type has brought keen interest from real estate investors seeking to cash in on the outsized gains possible in this nexus of the real estate and tech sectors. Investors seeking to become landlords of the Internet are in for a disappointment, however, when it comes to evaluating these investments, as data center investment defies easy categorization as either industrial or commercial property. The evaluation metrics

and rules of thumb that may apply to investments in safer and more conventional real estate products fall apart when being applied to this new category. Furthermore, the dearth of past investment information means little is understood about the cyclical nature of the sector. With the exception of (Chegut 2013) for the New York CBSA, little is known about the performance history of this sector in the US and risk and return benchmarks are therefore elusive.

### **Supply and demand distinct market characteristics**

Perhaps the stickiest wicket of data center investment analysis would be quantifying demand and supply for a given market, or even in defining what constitutes a 'market' at all. Given that the Internet is largely omnipresent and omnidirectional, the catchment area of a market is determined largely by the presence of invisible infrastructure such as fiber optic cable or the availability of electrical power. Considerations such as population growth and density play a role in addition to primary considerations such as tax incentives, infrastructural security and climate.

### **Emerging technologies that could disrupt the data center market**

Investors in the data center market may also be concerned with technological obsolescence of these facilities. Unlike office or multifamily assets, data centers are a relatively new product whose depreciation schedules are governed not only by entropy but by technological innovations that could make these facilities obsolete. Technological changes in the data center market could potentially make an investment obsolete in a much faster manner than could be dreamt of in more conventional real estate investments. The miraculous progress of Moore's Law over the past 40 years has struck fear in investors worried that exponential increases in computing power would lead to exponential declines in data center space demand. Likewise the rise of innovations such as Solid State Drive (SSD) replacing conventional Hard Disk Drives (HDD) threaten to shave power demand for existing customers as they upgrade hardware. The rise of cloud computing over the past decade has led many potential investors to fret that 'the cloud' would slowly consume all remaining demand for space and destroy the industry. With this new market we must fashion new tools and new metrics by which to understand and evaluate potential investments and threats to the business model.

This paper seeks to address and understand the kinds of underwriting issues that may affect data center valuation. It will be of keen interest to examine possible threats to the business model of the conventional data center facility and to wager a guess at possible directions the industry may go, given an absence of exogenous factors. Topics such as the effects of Moore's Law on power and space demand and the rise of cloud services will be center stage.

Currently the industry is new enough not to have much shared knowledge concerning the threats and opportunities to the sector. Very little information is available for open discourse. As such, this paper seeks to start the process of opening data center investment knowledge to one and all.

This paper will establish metrics for understanding real estate market demand and also establish means of understanding threats to market demand for data center investors or operators seeking to prognosticate the impacts of technological changes to their bottom lines. As with all things in real estate, the future is uncertain but disciplined dissection of market behavior is the first step toward projecting investment performance. One of the goals of this paper will be to offer a solid set of tools for translating advances in computational capacity, thermal and power efficiency into data center space and power demand.

The remainder of this thesis is outlined as follows. Chapter Two will examine the broad categories under which different determinants of data center value can be categorized. Chapter Three will attempt to summarize all the systems that comprise a data center facility. Chapter Four will address the rise of cloud computing and this technology's likely impacts on data center demand. Chapter Five will likewise address Moore's Law and its effects on data center demand. Chapter Six will attempt to summarize all the information that is known of the data center asset market in the United States, including but not limited to the REIT market. Chapter Seven will attempt to explain and nuance the DiPasquale and Wheaton Four-Quadrant model that is so commonly used to chart supply and demand in real estate markets. Chapter Eight will present new research on data center demand in the US, particularly with interest in early indicators on the health of the data center marketplace. Chapter Nine will present similar research on data center supply and the characteristics of most data center development in the US. Chapter Ten will seek to integrate all these chapters into actionable data center intelligence for the data center marketplace.

## **Chapter 2: Drivers of Data Center Space Demand**

When comparing data center development to more conventional real estate products, the greatest difference is that 'data centers are designed for computers, not people.' (Brown et al. 2008) As such, location is evaluated in distances from fiber and power, and distances are judged in travel time for photons, not cars. Data center development is capital intensive and technologically demanding. In this new real estate product type varies so extremely from its human-centric cousins that new metrics for value assessment are in order. The main factors determining value for data centers are intrinsic attributes, geographic attributes, infrastructural attributes, and tenant mix.

### **Intrinsic Attributes**

Intrinsic attributes are the features and systems within the data center buildings that ensure performance and confer value. These features would include such things as power density, site resilience and security, access to power, HVAC performance and capacity, resource management and power backup systems performance. The power density of a given facility is an important indicator of the flexibility of any data center because low-power-density facilities cannot accommodate much computing. Conversely, a well-managed, high-power density facility commands higher rents and offers greater relevance and flexibility as power requirements increase for data center tenants. High power density facilities can accommodate any mixture of tenants from low-power telecom tenants to high-power research computing and are less likely to become obsolete as the market evolves to accommodate more demand for space in which to operate high-density computing machinery. Likewise a data center facility with excellent resource management systems will outperform its rivals in efficiency and uptime (Moore et al., n.d.) and would therefore command a premium. Site resilience and security are features that speak to the likely performance of a data center during or after a disaster, whether manmade or natural. Intrinsic attributes are the features of a particular facility that convey value within the four walls of the asset, independent of attributes that involve the outside world.

### **Geographic Attributes**

Geographic attributes include characteristics such as location, proximity to population, climate attributes and agglomeration benefits. These are effectively all the benefits of a given location, less the infrastructural attributes that follow in the next section. Climate benefits would include absence of adverse weather conditions and extreme temperatures that would impede the performance of the cooling systems. As data centers are primarily designed to allow computers to compute and share information, agglomeration confers a great deal of value, as suggested by Equinix founder Eric Troyer; "the goal of coming into sites like ours is to create as many vectors out to the logical Internet as you can. The more vectors, the more reliable your network becomes – and generally the cheaper it

becomes because you have more ways to send your traffic.” (Blum 2012, pg. 118)

Agglomeration benefits are the value conveyed to a facility by virtue of that facility’s proximity to other data center facilities or perhaps other tenants within the same large facility. The benefits of agglomeration are not immediately obvious but are demonstrably connected to higher resale values (Chegut 2013). This phenomenon is nuanced by geographic characteristics such as centrality or proximity to transcontinental fiber landings that can elevate certain data center markets by virtue of their value as transfer stations of data from one agglomeration point to the next:

The prominence of Amsterdam and Stockholm in Europe and of Salt Lake City and Atlanta in the United States suggests that new clusters can emerge. London and New York remain important, if only because of the agglomerations of cumulative investment they represent (Malecki 2009).

These attributes are those that convey value on a facility due to its location but independent of the infrastructural aspects of that location.

### **Infrastructural Attributes**

The infrastructure category includes such characteristics as the amount of water available to the facility for cooling, the quality of the building’s construction and design, the quality of the building systems that ensure uptime, the roads leading to the building, or the bandwidth and fiber optic infrastructure available to the facility. Bandwidth concerns the facility’s access to sufficient fiber optic cable to move large amounts of information. Another concern would be the resilience of that fiber path or paths that feed the facility in question, as fiber optic lines are not well protected. An example of this came when a 75-year old woman accidentally cut off Armenia’s Internet with a garden shovel (Lomsadze 2011). Fiber optic infrastructure is routinely compromised through accidents, vandalism and construction, making multiple fiber feeds and redundant fiber paths a primary concern for any data center operator or tenant. Another infrastructural attribute would be the facility’s proximity to an international submarine fiber optic cable. Submarine cables are the means by which the majority of Internet traffic traverses the globe, making fiber landfalls the 21<sup>st</sup> Century equivalent of deep water ports for global information traffic.

### **Tenant Mix**

The tenant mix of a facility is a valuable trait as it determines the income stream of a given data center and thereby the value of the facility in the asset market. The ‘stickiness’, or demand inelasticity and infrastructural investment intensity of data center tenants, is legendary amongst players in the market.<sup>1</sup> In

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<sup>1</sup> Ty Bennion, Hines’ Managing Director for the Pacific Northwest, mentioned that the capital intensity of the tenant improvements (often over \$1000/sf) and the fear of downtime has meant that they have never lost a data center tenant to anything other than a merger. He added approvingly ‘I love these tenants – they never leave!’

past years, this concern led data center tenants to option extra capacity within a building regardless of whether or not it was needed. This practice may subside with the growth of on-demand cloud services that may be able to bridge any IT shortfalls in the short run.

Traditionally it has been hard to assess the value of a data center using anything other than NOI, however the combination of these attributes will form the basis for a fair valuation in addition to NOI and prevailing cap rate information.



## Chapter 3: Facilities

If the term 'data center' sounds uniform and monolithic, the reality is different. Data centers come in many sizes, ranging from relatively low-power density facilities engaged in routing information from one corner of the world to the next, or high-power density facilities engaged in crunching numbers for the latest Pixar movie or genomic sequencing. Data centers are about as standardized across the country as power plants or airports; they are used for many purposes and consequently have different designs. Facilities like the Massachusetts Green High Performance Computing Center (MGHPCC) in Holyoke, MA, shared by MIT, Harvard, Boston University, Northeastern and the University of Massachusetts, is used almost exclusively for large batch-computing research. Other facilities such as Hines Interests' Fisher Plaza in downtown Seattle work as carrier-neutral colocation facilities for medium and small scale tenants whose primary concern is uptime and accessibility from their firms' headquarters. Some are squirreled away in the top floors of buildings in busy downtowns, others are planted far from any city where climate, fiber optic or power considerations dictated the site's selection. Figure 1 shows an aisle of a data center that has primarily been configured for heavy-duty computation. Note that the hot aisle has been contained in this instance.



Figure 1: One of several of MIT's computing clusters at MGHPCC.

Just as the Internet is an ad-hoc series of interconnected networks that grew organically over time, the idea of a centralized building for hosting and connecting computer equipment similarly took shape. Many of these facilities were built into telephone closets or disused office space in a moment of need and continued on for lack of better space. The concept of a data center, a central facility for the exchange of data, has existed since the dawn of the telephone

age. The modern-day data center, however, came into widespread understanding after the passage of the High Performance Computing Act of 1991, which allowed private firms to build the physical infrastructure of this new medium (Blum 2012, pgs. 63-64). These NAPs would supplant the National Science Foundation-owned Internet infrastructure that had driven the Internet until that point and would allow for commercial and non-academic, non-government activity online as well. With that passage of this bill, the floodgates were opened to explosive growth and with it a new problem; no one really agreed on what to build or how to do it. The design of the earliest data centers was a result of short-term need. Early ISPs and corporate IT departments needed facilities in which to connect to the nascent Internet and lacked the any facilities that could do the trick (Blum 2012, pg. 59). As this space demand grew apace with the growth of what we now understand to be the Internet, the modern data center came into being. This new building type was largely defined as a facility that sits on a fiber network that consumes large amounts of power for computation, storage and routing and cooling. With the early history of the product type established, let's look into some of the components of these structures that separate them as a separate class of real estate assets.

## **Power**

The electrical and mechanical systems designed to deliver power to computer equipment and to remove the resulting hot air. What's most remarkable about data center design is not the systems involved, but their scale; a typical facility of medium size can deliver several megawatts of power to the buildings' computer equipment and then expel all the heated air, transforming all that power into heat and then pushing the heat out of the building. All the equipment in the building acts in concert to turn all the power going into the building into heat, and the byproduct of this is a correctly routed electrical signal.

Data centers use incredible amounts of power and their consumption has been increasing rapidly. One early glimpse into the sector's energy use in 2000 concluded that all US data centers used approximately 0.12% of the nation's electrical capacity. (Mitchell-Jackson et al. 2002) By 2010 that same figure had expanded to approximately 2% (Koohey, Ph.D. 2011). In 2011, environmental watchdog Greenpeace lamented that "data centers to house the explosion of virtual information currently consume 1.5-2% of all global electricity; this is growing at a rate of 12% per year."(Cook and Van Horn 2011, pg. 5) The follow up report in 2012 revised their earlier statistic much higher to ~20% annually ("How Clean Is Your Cloud? Catalyzing an Energy Revolution" 2012). These facilities use enormous amounts of energy, and the sector's consumption is growing rapidly.

As power is the main input and typically the largest single expense for a data center, one would assume the industry, whose sensitivity to location is dictated by the speed of Internet traffic rather than physical traffic, would locate only in areas offering cheap power. This has partially been the case. Agglomeration points such as the town of Quincy in Eastern Washington State offer little in the way of amenities, but what the town lacks in creature comforts it



compensates with extremely cheap electrical power (Glanz 2012). Similar reasoning was behind Google's construction of a large data center nearby in The Dalles, Oregon, just downriver from Quincy, and Facebook's construction of a flagship data center in Prineville, OR. All these facilities took advantage of tax breaks, strong fiber optic infrastructure and extremely cheap power with less consideration given to proximity to large population centers (*The Economist* 2008).<sup>2</sup>

Though the huge power consumption of a given data center was previously seen as a fact of life, increasing scrutiny of the sector by the EPA and Greenpeace have cast light on how wasteful many of the industry's designs and operating standards have been. Greenpeace in particular seems particularly keen to call attention to firms for their power sources rather than power utilization effectiveness, shaming firms who use utility power and coal-fired power sources over greener alternatives (Cook and Pomerantz 2015).<sup>3</sup> What would be of more value to analysts of the industry would be greater transparency regarding the PUE of individual data center facilities. When pressed for recommendations on how to handle increasing power consumption by the industry in their 2007 report to Congress, the EPA's first recommendation was for standardized efficiency metrics and reporting for all US data centers (Brown et al. 2008, pg. 13). Though some of the largest operators of data centers in the world such as Google and Facebook tout their PUEs like a car manufacturer would an MPG rating, the majority of the industry has remained silent on what percentage of their consumption is wasted. The average PUE rating of a facility has improved modestly since the government began its original inquest:

The EPA's Energy Star program set up a measurement protocol for PUE and found a mean PUE for 61 data centers in 2010 of 1.92, and a range from 1.36 to 3.60. The first annual Uptime Institute Data Center Industry Survey conducted in 2011 showed an average PUE of about 1.83 (Koomey, Ph.D. 2011, pg. 4).

This means that the average data center used at least 0.83 Watts to deliver 1 Watt to their tenants, and in many cases they were doing far worse. If this metric is more widely reported and scrutinized, the industry is more likely to change its behavior and upgrade or scrap its most wasteful facilities.

Data center power consumption is an area of growing concern to environmentalists, governments, tenants and owners. While a fair amount of research has been done on how best to economize data center power

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<sup>2</sup> John Sheputis, President of InfoMart Data Centers mentioned in a conversation that the driving decision behind their expanded push into Oregon from California is not simply cheap land and power, but rather favorable tax conditions, including both a lack of sales tax and property taxes on data centers. He then went on to say that the tax burden of operating in more conventional markets marginally outweighs power costs and other operating expenses in a given year.

<sup>3</sup> Power Utilization Effectiveness, or PUE, is the industry metric that determines how much of the power going into a data center is ultimately delivered to the rack level. In other words, if a facility has a PUE of 1.5, 1 Watt of the 1.5 makes it to the racks and the additional 0.5 Watts is used up in cooling, power delivery, UPS infrastructure, and other extraneous systems. In this regard, the perfect PUE score would be a 1.0, although there are several in the field who have theorized that a PUE of less than 1 is technically achievable (Haywood et al. 2012, pg. 1)

consumption, this is a relatively new field whose players are only recently adopting common terminologies with which to diagnose problems. (Pelley et al. 2009) The large savings to be realized by owners and the environmental benefits of increased power efficiency will spur greater and greater investment in this field for some time to come.

### Tenant Composition

Not all data center tenants are alike; the unique mixture of computing activities they're engaged in determines their power signature, bandwidth and cooling needs. By and large, the three activities a tenant will engage in fall under three categories: processing, storage and routing. If a data center were to be compared with a factory, processing would be production, storage would be the inventory of the factory and routing would be the shipping dock that bundles the product and sends it on its way. Processing activities require large amounts of processors and power in order to achieve a result. Data mining, digital rendering and search requests all fall under this category. Tenants engaged in large amounts of processing tend to need large amounts of power from high power-density facilities with similarly powerful cooling systems. The MGHPCC facility previously discussed was designed primarily for this kind of tenant.

Data storage is also a power-hungry activity. One might assume that an application of Moore's Law to the storage market would halve demand every 18 months as memory density and efficiency both increase in tandem. Though storage systems and capacities have been growing in size and efficiency at roughly the same pace as Moore's Law, global demand for digital storage space has been increasing at between 50%-70% per year (Kant 2009, pg. 2948). Even with the remarkable increases in storage density and efficiency, demand for storage is rapidly increasing even as the cost of storage per gigabyte is plummeting. This current relationship is unlikely to change with the further refinement of the SSD, whose chief advantages are speed and power economy. Data center tenants have been using SSDs now for some time although as of this writing HDDs still offer marginally more capacity per dollar.<sup>4</sup>

Routing is the final element in this picture and no less important, although it is far less power-hungry.<sup>5</sup> Routing is the workaday business of the Internet; packaging and delivering data from one point to another. Data centers function as physical nodes in which to run cables and connect the hardware from one network to another. The physical cables that run from one rack, cage or corner of the building to another are the highways of glass and copper that conduct our data from one carrier, website or network to another. Even though routing itself if

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<sup>4</sup> Sheputis mentioned that the tenants that had switched to SSD-based servers were replacing their equipment closer to every 5 years rather than every 3, noting that SSDs are not prone to catastrophic failure and that SSDs slow down predictably as they end their functional lifespans. In this regard SSDs offer greater operational savings (increased lifespans) and far greater functional performance.

<sup>5</sup> In a field visit to MGHPCC, one technician casually mentioned they budget 22kW per rack of processing equipment, 6 kW per rack of storage equipment and 3 kW per rack of routing equipment, making processing the most power-hungry activity by far.

not a power-intensive activity, selling the rights to connect one router to another across a carrier-neutral facility can be every bit as remunerative as selling power. This is one of the few instances in the data center world where income comes from something other than selling power. Entire data center facilities are built and tenanted purely for routing activities; PAIX in Palo Alto is among the most famous of these facilities. Equinix derives upwards of 20% of its revenues from interconnection fees alone.<sup>6</sup> Equinix (EQIX) is easily the largest of the publicly-traded REITs that specialize in data centers and their approach has been to focus on central facilities that specialize in routing and interconnection rather than storage or computing, as other REITs such as DuPont Fabros or Digital Realty Trust, whose business trends more toward wholesale data center leasing for corporate clientele.

## Cooling

Data Centers generate heat, and the mechanical systems of these facilities are what manage this heat. There has been a great deal of discussion surrounding the best way to manage heat in a data center – early systems kept the computer equipment chilled at temperatures usually reserved for the dairy aisle at the supermarket. As data center design has progressed, computer racks have been organized in such a way that intake (cold) and exhaust (hot) aisles alternate throughout the floor. Typically each of the computer racks is raised 18-36 inches above the floor on a raised floor that both conducts cold air in and hides much of the cabling that powers and connects the computer equipment in the racks.

There has been a debate within the data center design community over the next step to take in cooling efficiency. Hot and cold aisle containment appears to be agreed upon, however the fate of raised-floor cooling systems is not. Raised floors offer the double-benefit of concealed cabling and ducting cold air. The downside to this is that the air is not necessarily delivered evenly or predictably through the plenum (Patankar 2010), the cabling can be difficult to access and maintain, the plenum can be difficult to clean, and they offer limited seismic and load support, particularly as IT equipment is extremely heavy (Brill 2007, pg. 6). Some have opted instead to dispense with the raised floor and return their racks to solid ground, opting instead for liquid-cooling systems that pump chilled water to cooling fans on the outside of the hot aisle containment pods.<sup>7</sup> Other researchers have touted the superior efficiency of water-based cooling all the way down to the servers themselves, entirely avoiding the matter of cooling air, (Zimmerman et al. 2012) or of using absorption chillers to harvest the energy in a data center's heated air in order to lower PUE. (Haywood et al. 2012) No matter which technology ends up dominating data center design, the operative benefit will be allowing data center operators greater control over which

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<sup>6</sup> <http://www.sec.gov/Archives/edgar/data/1101239/000119312515359693/d45347d10q.htm>

<sup>7</sup> Such liquid cooling systems have been gaining in popularity according to conversations with representatives from T5 Data Centers, one of the larger private REITs active in US data center construction and operation.

	<ul style="list-style-type: none"> <li>• Concurrently maintainable site infrastructure with expected availability of 99.982%</li> </ul>
4	<ul style="list-style-type: none"> <li>• Meets or exceeds all Tier 3 requirements</li> <li>• All cooling equipment is independently dual-powered, including chillers and heating, ventilating and air-conditioning (HVAC) systems</li> <li>• Fault-tolerant site infrastructure with electrical power storage and distribution facilities with expected availability of 99.995%</li> </ul>

Figure 2: The Uptime Institute's tier configuration criteria for all four tiers.

Google describes the Uptime Institute's tier ratings system as being useful, but somewhat hampered by a lack of verified participation:

Formally achieving tier classification certification is difficult and ...[so] most datacenters are not formally rated. Most commercial datacenters fall somewhere between tiers III and IV, choosing a balance between construction cost and reliability. Generally, the lowest of the individual subsystem ratings (cooling, power, etc.) determines the overall tier classification of the datacenter. Real-world datacenter reliability is strongly influenced by the quality of the organization running the datacenter, not just by the design. The Uptime Institute reports that over 70% of datacenter outages are the result of human error, including management decisions on staffing, maintenance, and training. Theoretical availability estimates used in the industry range from 99.7% for tier II datacenters to 99.98% and 99.995% for tiers III and IV, respectively (Barroso et al., 2013, pg. 48)<sup>10</sup>

Although the marginal difference between a 99.7% uptime and a 99.995% uptime would seem insignificant, the numbers make more sense when multiplied by 8,766 (number of hours in year), at which point the difference between a tier II and tier IV facility works out to being 25.86 hours/year of uptime, a staggering difference.

What the tier ratings system offers is a preliminary understanding of the reliability and durability of the power, information and mechanical systems of a given facility. This approach has been useful in quantifying the desirability of different facilities and in valuation of these assets.

Any discussion of tier-levels and UPS power-systems performance should include the debate over the relative advantages of different systems designs. The most common UPS systems in the US rely on batteries for backup power.

<sup>10</sup> In previous experience rating data center facilities, Seattle data center broker and facility-manager Ed Doyne suggested the majority of commercial, non-government data center facilities were between tiers II and III and that the incremental cost of developing a facility to a higher tier level would add a great deal of additional design, mechanical and electrical work per tier.

power to heat as the line voltage is transformed from AC to DC and back to AC. (Barroso et al., 2013 pg. 50) Many firms are attempting to tackle the challenge of economizing UPS systems, either by putting battery-based UPS at the server-level or attempting fewer power transformations by designing an all-DC data center. (Ton et al. 2008)<sup>8</sup>

### Service Level

The strength of a data centers' power and UPS systems is the largest indicator of service level and the rates that the facility's owner can charge. A well-designed, easily maintainable UPS system is an indication that a facility was purpose-built for computing and not created as an afterthought. Much of the data center product available on the market was not originally designed for industrial computation and is less likely to offer acceptable performance. Quantifying the suitability of a facility for such high-level computing demands has traditionally been difficult. The service level of a data center is now quantifiable on a scale designed by The Uptime Institute, whose tier-based service level ratings system is the lingua franca. The Uptime Institute neatly folds all data centers into four tiers, with one being the lowest and four being the highest. Table 1A shows the current tier system as designed by the Uptime Institute, with each successive tier offering higher service levels than its predecessor.

Tier Level	Requirements <sup>9</sup>
1	<ul style="list-style-type: none"> <li>• Single non-redundant distribution path serving the IT equipment</li> <li>• Non-redundant capacity components</li> <li>• Basic site infrastructure with expected availability of 99.671%</li> </ul>
2	<ul style="list-style-type: none"> <li>• Meets or exceeds all Tier 1 requirements</li> <li>• Redundant site infrastructure capacity components with expected availability of 99.741%</li> </ul>
3	<ul style="list-style-type: none"> <li>• Meets or exceeds all Tier 2 requirements</li> <li>• Multiple independent distribution paths serving the IT equipment</li> <li>• All IT equipment must be dual-powered and fully compatible with the topology of a site's architecture</li> </ul>

<sup>8</sup> Joe Kava mentioned that Google had looked extensively into the benefits of an all-DC data center and had judged that the benefits (substantial power savings, substantial heat savings) did not outweigh the risks (increased chance of death by electrocution). This may be an idea like the hydrogen-filled dirigible; incredibly strong and efficient, but perhaps not ready for prime time.

<sup>9</sup> <https://uptimeinstitute.com/research-publications/asset/tier-standard-topology>

- 4
- Concurrently maintainable site infrastructure with expected availability of 99.982%
  - Meets or exceeds all Tier 3 requirements
  - All cooling equipment is independently dual-powered, including chillers and heating, ventilating and air-conditioning (HVAC) systems
  - Fault-tolerant site infrastructure with electrical power storage and distribution facilities with expected availability of 99.995%

Figure 2: The Uptime Institute's tier configuration criteria for all four tiers.

Google describes the Uptime Institute's tier ratings system as being useful, but somewhat hampered by a lack of verified participation:

Formally achieving tier classification certification is difficult and ...[so] most datacenters are not formally rated. Most commercial datacenters fall somewhere between tiers III and IV, choosing a balance between construction cost and reliability. Generally, the lowest of the individual subsystem ratings (cooling, power, etc.) determines the overall tier classification of the datacenter. Real-world datacenter reliability is strongly influenced by the quality of the organization running the datacenter, not just by the design. The Uptime Institute reports that over 70% of datacenter outages are the result of human error, including management decisions on staffing, maintenance, and training. Theoretical availability estimates used in the industry range from 99.7% for tier II datacenters to 99.98% and 99.995% for tiers III and IV, respectively (Barroso et al., 2013, pg. 48) <sup>10</sup>

Although the marginal difference between a 99.7% uptime and a 99.995% uptime would seem insignificant, the numbers make more sense when multiplied by 8,766 (number of hours in year), at which point the difference between a tier II and tier IV facility works out to being 25.86 hours/year of uptime, a staggering difference.

What the tier ratings system offers is a preliminary understanding of the reliability and durability of the power, information and mechanical systems of a given facility. This approach has been useful in quantifying the desirability of different facilities and in valuation of these assets.

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Another option is to go with kinetic-energy storage systems such as flywheels for power storage. Both systems have their merits; battery-backed UPS systems are known for being cheaper, flywheel systems are known for being more space and power efficient. Both systems have been known to fail, and neither system can be said to be “cheap”. Both systems require careful maintenance at regular intervals and can only be expected to perform for minutes at a time.<sup>11</sup>

Given that UPS and generator systems tend to be among the most expensive portions of a data center, some industry players skip them altogether. As in the MGHPCC, facilities primarily dedicated to computation rather than storage can comfortably run off utility power and risk losing several minutes or hours per month of uptime in exchange for dramatically lower construction and operations costs.<sup>12</sup> Some in the industry predict data center designs that eschew UPS systems altogether in favor of a network of geo-diverse and geo-redundant facilities to ensure service levels (Greenberg et al. 2008, pg. 73).

## Performance and Energy Consumption

Any discussion of data center performance must involve energy consumption and efficiency. No one expects that these facilities are environmentally friendly, given the amount of power they draw and the amount of heat they expel. One source of frustration, however, has been the difficulty of predicting just how much power will be consumed by the sector in a given year (“How Clean Is Your Cloud? Catalyzing an Energy Revolution” 2012, pg. 9). While part of the problem in predicting national IT power consumption is a lack of transparency, the rapidly changing technologies that drive data center power consumption compound the problem. The famous 2007 EPA report estimated ‘data centers consumed about 61 Billion kilowatt-hours (kWh) in 2006, roughly 1.5% of total US electricity consumption, or about \$4.5 Billion in electricity costs’ and went on to estimate that ‘in 5 years the national energy consumption by servers and data centers is expected to nearly double, to nearly 100 Billion kWh’ (Brown et al. 2008). This report projected that the sector would become one of the larger industrial power consumers in the US in a relatively short period of time.

The EPA report was an early examination of the resource footprint of the IT sector that opened the door for other researchers to attempt to refine these projections. Subsequent studies of the likely power signature of the sector have revised the EPA’s estimate down to the point where the 2010 power footprint of the sector ranged between 1.7% to 2.2% of national power consumption,

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<sup>11</sup> What is notable about the divide between the two systems is that the US relies almost entirely on battery-backed UPS systems while Europe and the rest of the world are more reliant on flywheel energy storage.

<sup>12</sup> Only 20% of MGHPCC’s critical load is backed up with UPS and generator sets, and that corresponding portion of the critical load is reserved for storage and routing activities that cannot afford to lose the uptime. Likewise Microsoft has taken the same path with their Redmond Ridge 1 Data Center in Redmond Ridge, WA, where they built a 57,000 SF facility for processing and testing software. This facility is run entirely on utility power with no backup systems at all, saving a tremendous amount of power, construction cost, space and operations cost.



significantly lower than the EPA's original estimate, in large part because of the economic downturn and improved efficiency strategies (Kooimey, Ph.D. 2011, pg. 7).

Almost all the power that enters a data center is transformed into heat and dumped outside. Worse yet, much of the power that goes into a data center is not used for critical load, but instead for ancillary systems. One estimate has it that the majority of the power used in a data center is consumed in power transformation and mechanical systems rather than computing (Kant 2009, pg. 2941). By reducing the number of power transformations and economizing the power path to the motherboard, much power could be saved and data center owners would find themselves writing smaller checks each month.

There has been a continuing discussion for some time now regarding the continued viability of Moore's Law with regards to heat output. Computing power can double every 18 months, but the heat resulting from such high-power computing has been increasing as well (Brill 2007, pg. 6). While thermal efficiency has been increasing, the relationship between the increases in thermal efficiency and transistor density has not been consistent.<sup>13</sup> An imbalance between the two could mean that Brill's worst nightmare might be realized.

Each Watt of power saved has the added benefit of reducing the overall heat load on the building's mechanical systems, thereby multiplying the power savings by saving the HVAC system from doing extra work. One such design would economize power losses by transforming the critical load from AC to DC power as it enters the building, thereby avoiding several loss-ridden transformation steps and eliminating the need for each server to carry an individual power supply (Ton, Fortenbery, and Tschudi 2008).<sup>14</sup> Suffice it to say that data center efficiency would benefit greatly from economizing power conversion and distribution within the facility, from the motherboard to the power vault.

Several technologies under development could save large amounts of power when incorporated into data center design. A great deal of research is currently going into optimizing data center power consumption through economizing power routed to dormant machines. So-called 'zombie servers', if left unmonitored, can consume large amounts of power even when idling for lack of any work and large data centers with unpredictable work loads frequently find

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<sup>13</sup> Two other 'laws' of computing, Kooimey's Law and Dennard scaling, both address this issue. Dennard scaling, named after its discoverer, noted that power consumption in chips typically stayed relatively constant by area, meaning that as transistors scaled down they tended to consume similarly reduced amounts of power. Kooimey's Law was related; Kooimey noted that performance per Watt was doubling every 1.57 years, marginally faster than Moore's Law had predicted. Sadly, both relationships broke down around 2006/7, at roughly the same period that Brill called attention to power consumption as being the biggest threat to Moore's Law.

<sup>14</sup> Another idea involves designing the data center's power systems to run on the 400/240 Voltage more common in Europe that would allow for one fewer transformation step. In this case, one impediment would be that HVAC equipment typically cannot run on these voltages and would require a special workaround. In both cases, heat load and power are saved by trimming down power transformations. This idea was put forth to the author in an email by Gary Gerber, owner of Gerber Engineering Inc. of Seattle.



themselves with idle hardware (Choo 2010). Other technologies such as use of absorption chillers (Haywood et al. 2012), liquid cooling (Zimmermann et al. 2012), airflow modeling (VanGilder and Schmidt 2005) and temperature optimization all promise to prevent needless energy from being spent. Other eyes are trained on how to reuse the colossal amounts of waste heat being expelled from data centers; one such project in Seattle is aiming to heat Amazon's new corporate headquarters with the exhaust air that previously would have been dumped outside ("Planned 12-Story Seattle Data Center To Recycle Waste Heat" 2015). In any event, the enormous amounts of energy being consumed and expelled by data centers is now coming sharply under focus, putting greater pressure on developers to deliver high-efficiency 'green' data centers that consume less energy. Technological and design improvements are in progress that promise to dramatically reduce the power consumption and carbon footprint of the average data center.

Another area of low-hanging fruit for data center energy economization would be found in the building's cooling systems. Data center cooling systems have traditionally been oversized refrigeration units designed to keep server racks chilled at temperatures usually reserved for grocery store dairy aisles. One reason cooling system efficiency is a primary concern is that as computing performance increases, the resulting heat management costs (shouldered by facility operators) can rise out of control (Kant 2009). The cooling system of any data center must be equally matched to the power delivery capabilities of the facility and capable of handling any tenant configuration.

Critical advances have been made in recent years first with the separation of the exhaust portions of the server racks (the 'hot aisle') from the intake portions (the 'cold aisle'). Leakage between the heated exhaust of the server racks and the chilled intake air is a big source of energy waste. It stands to reason that containing and separating the two streams will save a great deal in cooling costs.

The optimal temperature of cold aisles is a major point of discussion in the industry, which has come to the conclusion that the very low temperature cold aisles did little for the computer equipment efficiency. Recent ASHRAE standards have boosted cold aisle temperature recommendations to between 20 to 25 degrees Celsius<sup>15</sup>, with speculation that there is possibly more energy to be saved by increasing cold aisle temperatures further. Research has shown that while the electrical and computer equipment sees little performance alteration with marginal temperature increases, there is an efficiency plateau above which marginal savings in HVAC costs would be cancelled out by decreases in component efficiency at the server level (M. K. Patterson 2008, pg. 1167).

This leads to another potential source of energy savings in data centers: 'free cooling'. This refers to the idea of using unconditioned air for cooling rather than pulling in outside air and chilling it before pumping it through the racks. While this idea sounds intuitive, not all data centers have the luxury of cool outside air. Clusters of these facilities in Arizona and Florida have to run their HVAC systems all year long. Even as the marketplace adopts new technologies

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<sup>15</sup> ASHRAE, TC9.9

that may enhance performance and power economy in data centers, a location with an appropriate climate may be the greatest advance of them all (M.K. Patterson 2008, pg. 1174). Climate considerations may factor into more development level decisions as efficiency considerations gain foothold in the asset market for data center space.

This brings the discussion on to whether waste heat from data centers can be recaptured. Though this idea has been around in many forms (*The Economist* 2015), the potential to capture potentially megawatts of waste energy from data centers is an enticing prospect. Other ideas have surfaced, coupling heat reuse and alternative energy sources to design a theoretical data center capable of a PUE of less than one (Haywood et al. 2012). The prospect of recapturing energy from waste heat could be a transformative step for the industry and will be the focus of scrutiny and experimentation going forward.

## Chapter 4: Cloud Computing and the Data Center Market

The explosion of on-demand, pooled computing resources referred to as 'cloud computing' has left a remarkable impact on worldwide computing patterns and service levels. 'Cloud computing' is an umbrella term for all shared computing resources that enable firms to escape dedicated geo- or task-specific hardware that would ordinarily entail inefficiencies of use. The US government qualifies cloud computing as being defined by five characteristics: on-demand self-service, broad network access (across devices and platforms), resource pooling (infrastructure sharing), rapid elasticity (scalability), and measured (automatically metered) service.<sup>16</sup> There is an emerging lexicon within cloud computing that further dials in the concept and its arcana. These refinements include: *Software as a Service* (SaaS), *Platform as a Service* (PaaS) and *Infrastructure as a Service* (IaaS). Details are expounded upon below:

- *Software as a Service* (SaaS): This broad category describes a software licensing and delivery model in which software is offered as a subscription rather than as a fee-simple transaction. This software as a service is typically accessed either through a web browser or similar thin client to access the program, which is largely hosted by the SaaS provider. Examples of this abound in all sectors of computer software, ranging from gaming to office productivity solutions. This is the most common interaction level that the average consumer has with cloud computing; anytime we perform a Google search, upload photos to Flickr, or comb through our Twitter feed, we're using software as a service.
- *Platform as a Service* (PaaS): PaaS is a cloud offering wherein the platform hosting the web applications being offered as SaaS is the actual service. This enables SaaS developers to rent out the platform needed for such app development and free themselves from the software and infrastructure concerns that developing such a platform would entail. Examples of using PaaS are harder to give for the average web user, but platforms for web apps such as Amazon Web Services (AWS) or Google App Engine, both of which host the apps that web users interact with on a daily basis such as Adobe Creative Suite (AWS) and Feedly (Google). In this way PaaS is removed from public sight but essential to the quotidian operation of the Internet.
- *Infrastructure as a Service* (IaaS): Like its counterparts, IaaS is where all the backend infrastructure such as servers, storage and routing equipment are provided for clients in such a manner that they can run any number of computing tasks or platforms. This is different than traditional colocation in that there is no need to purchase any of the infrastructure being used; it's being rented on an as-needed basis.

Cloud computing is a technological advance that promises to make computing more efficient. Cloud computing involves partitioning IT services into more discrete components and renting them to tenants in various forms. In all its flavors, cloud computing offers greater scalability and uptime over legacy systems constantly in need

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<sup>16</sup> <http://www.nist.gov/itl/cloud/upload/cloud-def-v15.pdf>

of maintenance and upgrades.<sup>17</sup> It is important also to recognize that cloud computing is not a competitor to data center demand; cloud computing tenants are simply displacing more conventional means of building out IT infrastructure for firms of all sizes. Perhaps the greatest advantage of this new technological trend is that firms no longer need to spend as much building and operating latent IT infrastructure for surge events that happen perhaps once a year (Gmach, D. 2007). Cloud computing is a means toward streamlined and more efficient IT management and greater uptime, but management and distribution systems for such a lofty idea are still a work in progress (Wang, Ng 2010). Consequently, cloud computation is a tool that offers tremendous promise but is currently a complement to existing systems rather than a cost-effective replacement. Furthermore, security concerns will likely dog the industry until they can assure all potential customers that their information will forever be free of prying eyes and sticky fingers. As cloud computing systems are profitable for their purveyors, it stands to reason that they will always be more expensive for an IT customer than it would be for the same customer to own and operate their own IT systems. The advantage offered by cloud providers, in the words of Joe Kava, Google's data center operations executive, is that "you can rent the best in the business" from cloud providers, getting the latest software and best technicians that money can buy without any of the capex involved.<sup>18</sup> Cloud services are here to stay, but they will always be more expensive for firms to rely on entirely in lieu of owning and operating their own systems.

The great promise of cloud computing is not to reduce the footprint of IT systems, but rather to reduce waste by evenly distributing tasks across existing infrastructure at optimal levels. As the technological state of the art increasingly allows this, demand for data center space and power will temporarily be interrupted as existing space is economized. Data centers were formerly designed to accommodate peak loads for their tenants, involving much more capacity than any given firm would reasonably need to serve ordinary workloads. This strategy led to idled and wasteful IT infrastructure and inefficient power consumption. Simply put, before cloud computing, we had to build all cathedrals for Easter Sunday. The push toward inclusion of cloud computing solutions into IT strategies has been underway for the better part of a decade and has so far failed to dent data center space demand measurably. Furthermore, the footprint savings due to cloud services would be a one-time savings, after which demand would theoretically return to historical rates. As cloud offerings increase in capability and decrease in price, firms of all sizes will increasingly be able to augment their existing infrastructure with cloud offerings as demand temporarily spikes, allowing firms to flexibly scale their IT needs up and down without the corresponding CapEx and waste. This should lead to more modest data center footprints for firms and to greater data center space demand for cloud services firms whose products are being used. The effect of this shift should be for cloud firms to increase the size of their facilities (Greenberg et al., 2011 pg. 1). One of the keys to profitability in cloud operations is colossal scale and similar efficiencies of scale for operations (Greenberg et al. 2008, pg. 1). This will spur demand for larger-footprint data center product offerings. Past performance and the continuing advancement of computational capacity would suggest that high-power-density data center space will always be a necessity and will not change its current procession

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<sup>17</sup> In an interview with Mark Silis, Head of MIT's Information Systems & Technology department, he estimated that cloud-based systems were 25-30% more expensive than their fee-simple counterparts but were markedly more versatile and scalable, requiring far less work to maintain, fix and update. He estimated it would take a further 20 years to move all MIT systems to cloud-native apps but would be well worth the effort and expense.

<sup>18</sup> From an interview with Mr. Kava granted in Mountain View on October 22, 2015.

towards higher and higher power ratings. In summary, cloud computing is a tremendous technological feat that will allow firms to economize and scale their IT needs and data center space and power demands by eliminating waste and excess capacity. This technological development seems more likely to spur greater demand for data center space than it does to curtail demand for data center space.

This now brings us to a discussion of the likely effects on the data center space market as cloud computing resources become more flexible, cheaper and more secure. Cloud-based systems are not likely to become a universal panacea for all IT systems until nagging issues to do with data protection, privacy, price and security are solved. Firms with sensitive information and intellectual property are still loath to use cloud solutions when there is an iota of risk of theft or information leakage. As a result, cloud services are likely to become a larger portion of the data center space market, but will not monopolize the market for a long time to come. However, now that cloud services allow firms to optimize their data center footprints by removing inefficient and underutilized systems, there will be a movement within the data center marketplace for higher-power-density and lower-PUE data center spaces that will allow more efficient operations for the firms involved. In short, cloud services will push inefficient data center spaces further toward obsolescence as they slide down the depreciation slope of the 4-quadrant model outlined in Chapter 7 later in this paper.

## Chapter 5: Moore's Law and Data Center Demand

For all the discussion of data center systems and functionality, one of the most common questions encountered in real estate circles about the asset class is whether Gordon Moore's famous law poses a threat to the industry. If data centers exist purely to host the army of machines and those machines' power and efficiency double every 18 months, what prevents demand from disappearing as quickly? Will technological progress destroy the product type altogether? Some have suggested the next advances in computing or storage will drive a stake through the heart of the industry entirely, ignoring that the routing business should stay relevant no matter what. In the interest of studying the growth of the industry and its likely growth trajectory, let us seek to understand whether Moore's Law does in fact pose a threat to data center demand.

Moore's 1965 prediction that transistor density doubles roughly every two years grew from a modest projection and caught wind from there, being further refined in 1975 to the "Law" we cite today. Though it is not a physical law but rather an observation, it morphed into a self-fulfilling prophecy as semiconductor manufacturers timed their R&D spending and capex to match Moore's timetable. The law has been in place now for close to 50 years and has largely held true:

## Microprocessor Transistor Counts 1971-2011 & Moore's Law

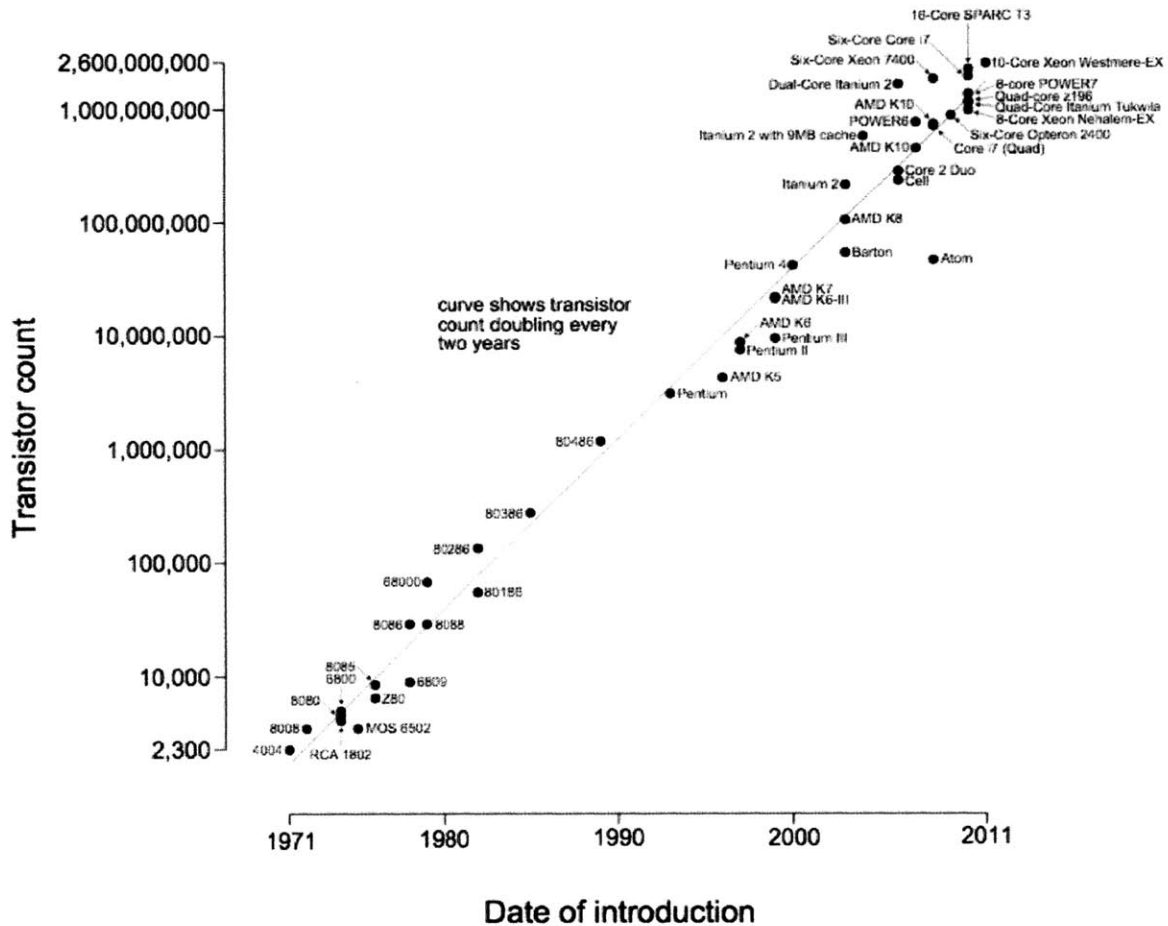


Figure 3: A visual representation of conformance to Moore's Law from 1971 to 2011, showing approximate compliance with the exponential rate of growth originally predicted. (Wikipedia 2015)

Moore's Law has been a useful means of predicting where computational capabilities will rest in the future. Though Moore himself has suggested that the law will not hold true forever (Courtland 2015), it seems likely to continue with new and novel chip designs poised to carry the flame for at least a while longer. The law has also been used to describe other technological growth patterns ranging from digital storage media density, photovoltaic panel efficiency and LCD pixel density. In each instance, these 'laws' are really budgeting targets that allow the industry to plot growth metrics and allocate resources accordingly.

Why, then, do firms continually expand their IT footprints as Moore's Law progresses? Data center tenants store and compute as much information as is economically feasible for them. When computing and storage costs fall, they expand their IT footprints to the limit of their budgets. With additional capacity, these firms store more and larger files, upgrade software and speed up processing capacity rather than shrink their IT footprints to match their existing needs. In other words, tenants pay as much as they do for data center presence

because their data is their most valuable asset. When the cost of storing and processing data falls, they keep more data.<sup>19</sup> This pattern has been borne out historically, as noted by Martin Hilbert and Priscila Lopez, whose research showed a 25% compound annual growth rate of information storage capacity between 1986 and 2007 (Hilbert and Lopez, 2011). McKinsey came to the same conclusion recently, adding that “data have swept into every industry and business function and are now an important factor of production, alongside labor and capital” (Big Data, McKinsey, 2011). Going further into the 21<sup>st</sup> Century, firms are realizing that their most valuable resource isn't what they make, but the information they have with which to make what they make. The progress embodied in Moore's Law has allowed these firms to store greater volumes of more sophisticated information add to their treasure trove.

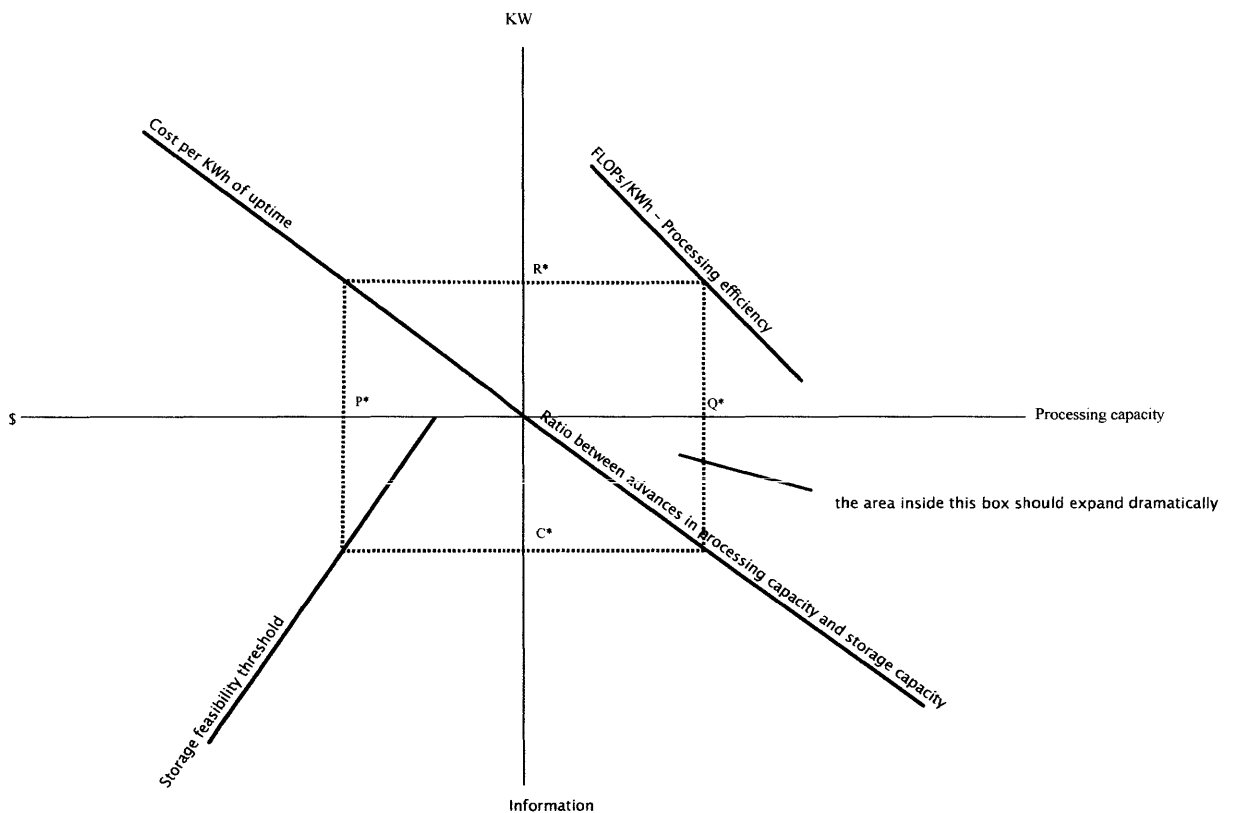


Figure 4: An adaptation of the DiPasquale-Wheaton model to account for the evolution of IT capabilities as a function of power consumption, cost and capabilities (both of storage and processing).

The fact that firms would expand their IT footprints indefinitely seems counterintuitive, but is not without precedent. Data center developers have frequently cited the works of William Stanley Jevons, whose eponymous paradox is seen in

<sup>19</sup> Sheputis mentioned that his clientele have found it is infinitely more valuable to keep data judged to be of no value than to discard it, finishing with “it is always cheaper to keep data than to delete it.”

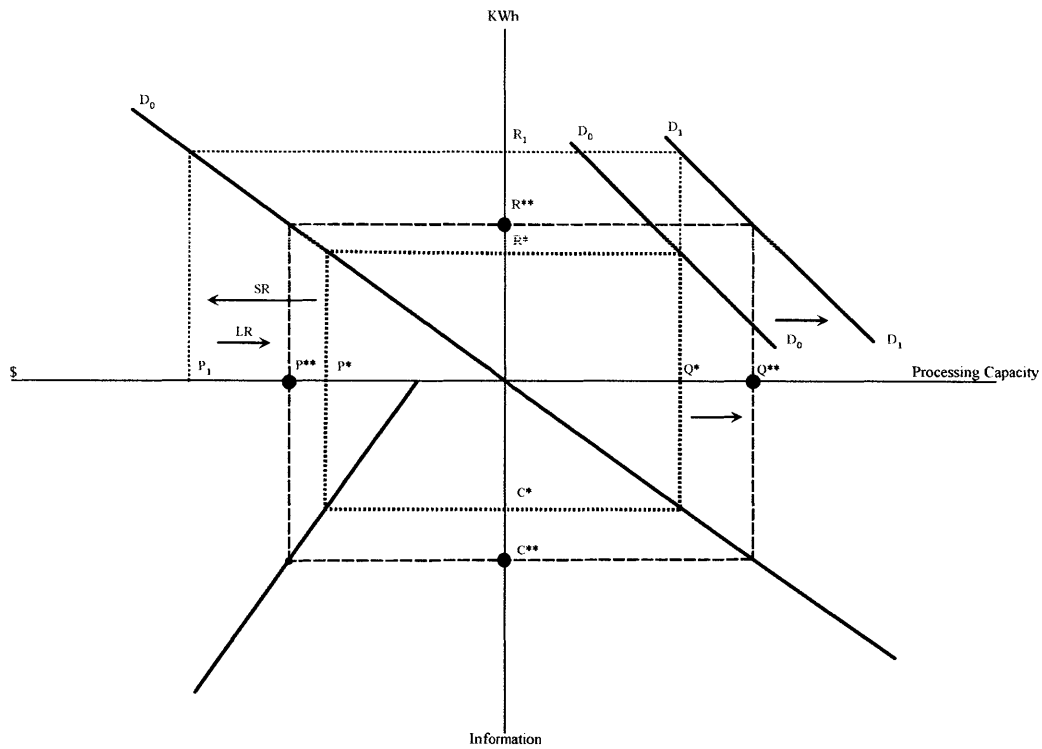


environmental economics, energy and resource consumption. The Jevons Paradox is applicable to any technological advancement that yields greater efficiencies which then, paradoxically, lead to greater consumption (Bauer, Papp 2009). The application to data center economics appears obvious; with processing capacity and power consumption improving, one assumes that data center tenants would use this advancement to cut costs. Rather, they use the added power and efficiency to double down on information storage and processing, creating greater value for their respective organizations.<sup>20</sup> This line of thinking goes on to suggest that such firms' appetites for information are likely limitless and are only bounded by such factors as heat production, processing lag, and cost. The steady march of Moore's law has been a stimulant to the data center market, as incremental technological progress has unleashed new computerized realms of investment that has created value for the firms that invest therein. Google's data center executive Joe Kava put it bluntly: "ironically, the real threat to the data center industry isn't Moore's Law – it's that it might stop."<sup>21</sup> The innovations that flow as a result of following Moore's Law unlock new markets and realms of investment that continually feed greater demand for data center space. The cost of data is not related to data center capacity demand; as processing and storage capacity fall in price and grow in power, data center tenants' IT footprints will continue to grow as their budgets allow. This is in keeping with Cesar Hidalgo's theory that firms are 'prevailing in our universe's only true war: the war between order and disorder, between entropy and information" (Hidalgo, 2015, pg. x).

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<sup>20</sup> Hines' Bennion again attested to this with "it's like clockwork; everyone takes more power, and they replace/expand their systems every three years. No one reduces their footprint – they expand in capability."

<sup>21</sup> From interview notes, interview on Oct. 22, 2015.



Source: Adapted from Geltner, Clayton, Miller and Eichholtz, 2013

Figure 5: The short-run implications of increases in processing capacity.

In conclusion, Moore's Law, and the technological progress embodied therein, serves as a boon to data center development, allowing firms to expand their IT profiles in greater and greater strides as the state of the art allows. This is particularly helpful to data center owners, whose facilities purely sell power, space, cooling and interconnectivity to their tenants, who then bear all the responsibility of updating and replacing their outdated tech. Those who fret that progress threatens data center demand fail to see that computers are not the true tenants of data centers; data is. And as long as its value outweighs the cost of storing it, tenants will continue to store more of it as prices fall. As long as information continues to be the most important product of human endeavor, the data center industry will grow.

## Chapter 6: Market Overview

The data center market is unlike those established for office or hospitality assets in the real estate universe; standardized data center performance and leasing metrics have been slow to emerge, and what little information we have is guarded closely. As such, we are only now seeing the market for data center space become a quantifiable space in which standardized metrics can be mined for insights, performance and prediction.

One critical component of the data center market that is heretofore missing is transparency. Unlike hotels, whose occupancy, rate and RevPAR information are openly available either through public record or third party vendors, information on data center occupancy, rate, capacity, efficiency, power and service levels are held secret. Oversight of performance claims is paltry at best. Power consumption information is rarely divulged and warrants skepticism if offered, as data center managers have little incentive to offer clarity to an uncompetitive market.<sup>22</sup> The greatest impediment to data center research to date has been an ironic lack of data, and there is little incentive for those in the industry currently to change this.

What little we know about the data center space market can be inferred from the past ten years of data center REIT performance. All seven of the publicly-traded data center REITs have shown admirable performance, particularly for the lack of the typical cyclicalality seen in other markets (and their REITs) such as hospitality or office. The publicly-traded data center REIT market did well enough to weather the 2008/2009 downturn with comparably notable poise:



Figure 6: Despite a collapse of the worldwide financial system, data center REITs performed handsomely during the downturn, particularly after January 2009.

<sup>22</sup> An exception would be the largest owners of data center space such as the US Federal Government, Google, Apple and Facebook. Google has made an effort to divulge data center efficiency and power information in limited quantities and regular intervals. One can assume this is a public relations exercise and not an effort to enlighten the marketplace.  
<https://www.google.com/about/datacenters/efficiency/internal/#measuring-efficiency>



And if long term performance paints a rosy picture for this sector's performance, the year-on-year returns are even more compelling. While we can't peer directly into the performance of the many private data center development firms and funds at work throughout the US, we can again use public REIT data. 2014 was a particularly productive year for the seven data center REITs, whose average return of 28.3% vastly outstripped the S&P 500's annual return of roughly 11.74%:

#### INDUSTRY GROWTH

Company	Ticker	Price*	Market Cap(S)**	2014 Return*
CyrusOne	CONE	\$27.55	1.08 B	23.4%
CoreSite Realty Corp.	COR	\$39.05	919 M	21.3%
Digital Realty Trust Inc.	DLR	\$66.30	9.5 B	35.0%
DuPont Fabros Technology Inc.	DFT	\$33.24	2.4 B	34.5%
Equinix Inc.	EQIX	\$226.73	11.7 B	27.8%
QTS Realty Trust	QTS	\$33.84	1.1 B	36.6%
Rackspace Hosting Inc.	RAX	\$46.81	6.7 B	19.6%
<b>Data Center Average</b>				<b>28.3%</b>

\*Price and 2014 Return are based on Morningstar closing share prices for 12/31/2014.  
 \*\* Market Cap based on Morningstar data from 1/13/2015.

Figure 7: 2014 data center REIT performance (CBRE).

Though these REITs cover different portions of the data center spectrum from networking to wholesale to retail, the picture looks equally rosy for all, given that their average performance for 2014 was markedly higher than average stock returns. These REITs are somewhat representative of the wider data center market throughout the United States; the market is still predominantly controlled by private developers whose activities are less transparent and more regionally focused. The overall cost of construction for a data center, in addition to the dearth of banks that are familiar lending on such a product type, precludes developers from doing many projects at a given time. A snapshot of regional markets in the US tells much the same picture. This CBRE-compiled chart shows a mixture of privately-developed and REIT-developed colocation space in the nation's top seven markets:

#### Q4 2014 PRIMARY WHOLESALE COLOCATION MARKET SNAPSHOT

Market	Inventory	Vacancy	Absorption	Rental Rates (kW/mo)*
Northern Virginia	402 MW (▲ 12.7 MW)	27 MW / 6.7% (▲ 13.0%)	8.9 MW (▼ 9.1 MW)	\$135-\$150
Phoenix	213 MW (nil)	4.1 MW / 1.9% (▼ 35.4%)	2.3 MW (▼ 1.7 MW)	\$145-\$165
Atlanta	127 MW (nil)	26.2 MW / 20.7% (▼ 8.7%)	2.5 MW (▼ 0.7 MW)	\$120-\$150
Silicon Valley	116 MW (nil)	15.9 MW / 13.7% (▼ 16.1%)	3.0 MW (▲ 8.1 MW)	\$145-\$150
NYC/NJ	122 MW (▲ 3.5 MW)	20.4 MW / 16.7% (▼ 14.5%)	6.3 MW (▼ 2.1 MW)	\$145-\$160**
Chicago	115 MW (▲ 2.5 MW)	3.6 MW / 3.2% (▼ 33.5%)	3.4 MW (▲ 1.9 MW)	\$145-\$165
Dallas/Fort Worth	113 MW (▲ 5.1 MW)	12.1 MW / 10.7% (▼ 27.4%)	8.9 MW (▲ 3.3 MW)	\$140-\$150

\*Rental rates are quoted asking rates from providers. CBRE experiences that actual contract rates fall below these numbers.  
 \*\*Quoted rates are outside of NYE proper. NYE (Manhattan) wholesale rates average \$225-\$300/kW/mo.

Source: CBRE Data Center Solutions Group, Q4 2014.  
 Arrows reflect quarter-over-quarter changes.

Figure 8: Supply and demand information for the US, Q4 or 2014 (CBRE).

These numbers are all approaching the same conclusion; the data center market will continue to do well assuming that a lack of fiber, power and expertise continues to constrain entry into the marketplace for ambitious would-be data center developers. Even if those constraints were to disappear overnight, the remarkable growth of internet adoption and the declining cost of digital storage suggests that firms will continue to need space in an expanding number of mission-critical computing facilities. For the time being, data centers appear to be a safe bet.

As mentioned earlier in this paper, the Internet's user base, data transaction volume and stored data are all growing at rates usually reserved for infectious diseases. A few projections from Cisco set the tone for the growth we can expect in the near-term. Cisco has provided a number of salient indicators of predicted demand between 2014 and 2019:

- Global Internet traffic in 2019 will be equivalent to 64 times the volume of the entire global Internet in 2005. Globally, Internet traffic will reach 18 gigabytes (GB) per capita by 2019, up from 6 GB per capita in 2014.
- Busy-hour Internet traffic is growing more rapidly than average Internet traffic. Busy-hour (or the busiest 60-minute period in a day) Internet traffic increased 34 percent in 2014, compared with 26 percent growth in average traffic. Busy-hour Internet traffic will increase by a factor of 3.4 between 2014 and 2019, while average Internet traffic will increase 2.8-fold. ("Cisco Visual Networking Index: Forecast and Methodology, 2014–2019" 2015).

The Internet is growing faster than we can build it.<sup>23</sup> It is safe to assume the complexity, difficulty and capital intensity of data center development ensure that demand will outstrip supply for the foreseeable future given that these facilities are so remarkably difficult and time-intensive to construct.

Though the growth of the Internet is vastly outstripping mission critical computing facility supply, data center demand is not homogenous across regional markets or product submarkets (colocation, enterprise, etc.). Pronounced regional differences in occupancies and quoted power rates in the CBRE colocation market snapshot above. Regional differences may owe to supply quality issues, tax burden, the costs of electrical power, latency issues, or simply a dearth of "server hugging" firms that insist on keeping their data center footprint nearby, no matter what the cost. Another factor affecting regional data center occupancy and leasing rates may be the idiosyncrasies of the North American fiber optic grid. We know enough about the data center asset market to be able to tease out relationships between the value of data center facilities in relation to the location of fiber optic infrastructure and population bases. Studies of data center locations and city populations have shown new hierarchies

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<sup>23</sup> Another line of inquiry for a separate paper is whether the 'induced traffic' effect of road building is at play in data center construction, or, in other words, whether the Internet use and traffic increases with data center construction, as has been documented in the case of road construction.

amongst global cities that counteract conventional global city-tier rankings and frustrate city rankings based on commercial volumes or population:

San Francisco, Washington, D.C. and Dallas generally outrank the much larger areas of New York and Los Angeles, suggesting that Internet accessibility is responding to a demand that is beyond, or different from, that measured by population alone. This finding is especially strong when bandwidth-weighted links are analyzed (Malecki 2009, pg. 407).

The same paper goes on to analyze the agglomeration benefits of short-haul versus long-haul fiber routes between metropolitan centers:

The largest interurban links are relatively short distance and have attracted a large proportion of the 41 firms that operate backbones to serve cities such as New York – Washington D.C.; Los Angeles-San Francisco; and Boston – New York. It is these high-traffic routes that have attracted investment by multiple backbone providers. On the longer-haul routes, such as San Francisco-Washington, D.C.; and Chicago-Seattle, there tends to be less competition (Malecki 2009, pg. 409).

If fiber optic infrastructure is what lays the groundwork for data center development, and the number and length of fiber optic routes determines the value of a node on the fiber optic grid, then part of the function for estimating data center demand would involve a cursory examination of the fiber optic routes emanating from any one point. This would largely be a function of geography and population base. As such, the value of tertiary and secondary markets would be poised to explode as the fiber optic network fills in the missing routes across nodes in North America.<sup>24</sup> The value of the rapidly expanding smaller networks that comprise the internet and drive most of its explosive growth has been documented by economists and computer scientists alike (Zhang et al., 2008). This analysis dovetails with another prediction for the data center market of the future; “we expect future data centers to be a lot more than simply bigger versions of those existing today....[they will be] distributed, virtualized, multi-layered infrastructures that pose a variety of difficult challenges (Kant 2009, pg. 2939).”

Both seem to predict a more distributed, less centralized and smaller series of data centers throughout the developed world as latency becomes a larger concern for firms and individuals using the Internet for cloud applications and entertainment. This prediction of greater distribution of data centers across a greater number of metropolitan markets in no way suggests that large enterprise facilities will suddenly become obsolete, only that smaller facilities closer to population bases will become increasingly important as computer use tilts toward

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<sup>24</sup> This avenue of inquiry regarding the relative value of data center assets in secondary and tertiary markets is largely compliant with the monocentric city model wherein the marginal profit from developing a property is highest at the periphery. Given that “transportation costs” in the digital realm are a function of fiber optic capacity and signal lag, the effective size of a digital “city” is much greater but subject to the same sorts of constraints originally envisioned by William Alonso, Richard Muth and Edwin Mills.

cloud applications and the fiber optic infrastructure of the country develops further.

## Chapter 7: The Data Center Four-Quadrant Model

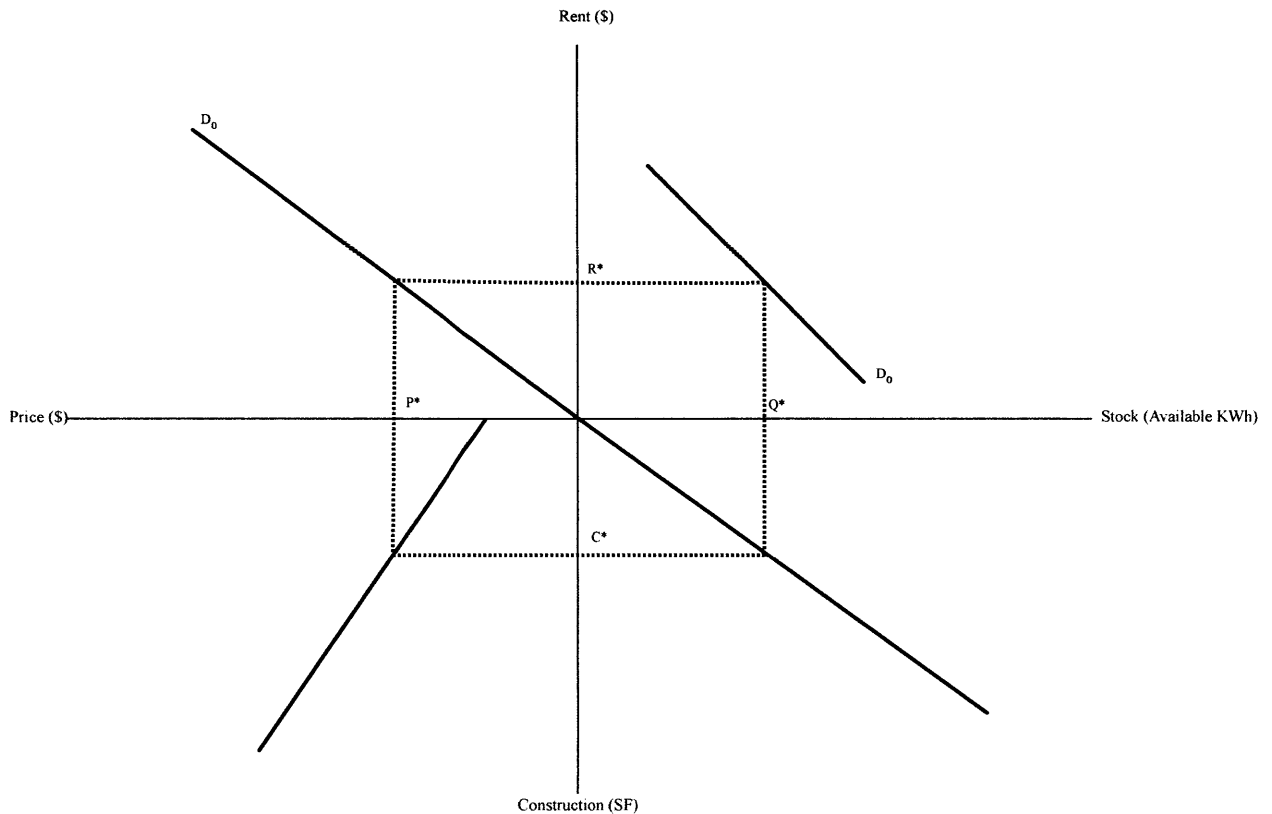
Traditional real estate products adhere to the DiPasquale and Wheaton model of short and long-term pricing and supply behaviors. This four-quadrant model shows the cyclical nature of demand shocks, price spikes, asset market price increases and the resulting increased supply that returns space market prices to their equilibrium point(s). The power of this model lies in its simplicity; the four quadrants react in concert to illustrate the effects that shocks in one quadrant have the rest of the system. As the system processes these effects, the market returns to its equilibrium state.

The data center market four-quadrant model departs from the DiPasquale and Wheaton four-quadrant model with the substitution of power (kWh) for space (SF). One critical difference between the conventional real estate market and the data center market is the measurement of product in kWh, a loose metric that determines the magnitude of the computing a data center tenant can achieve.

Power has heterogeneous demand and uses. It is tempting to attempt to equate the power measurement of a data center to an equivalent number of square feet using a conversion constant, however the diversity of data center power, UPS and HVAC configurations frustrates any efforts to arrive at an effective constant. Moreover, the diversity of the data center tenant needs would further complicate efforts to gauge demand using square footage; processor-heavy tenants such as universities use far more power than a routing- or storage-heavy tenants and therefore would offer misleading demand statistics if they were only gauged by physical footprint.

There is a hybrid measurement of data center power and space that the market uses: power density. This metric is denominated in Watts/SF and measures both the power load a facility can support (on average) per unit of space and also, by implication, the HVAC capacity of the facility to cool the resulting heat. With transistor density and computing ability growing by leaps and bounds each year, power density demands increase as well, although by smaller increments. A high-power-density facility will stay marketable and desirable for a longer period of time, much as a powerful computer will stay relevant and more useful for a longer period of time than a less powerful model.





Source: Adapted from Geltner, Clayton, Miller and Eichholtz, 2013

Figure 9: The DiPasquale-Wheaton four-quadrant model adapted for use in the data center sector.

Here is a synopsis of the changes made to the DiPasquale and Wheaton four-quadrant model for the purposes of adapting this model to the data center market. The quadrants have been altered to reflect the market's reliance on power for rent determinations.

The Northeast quadrant is where the market structures differently. The X-axis is now denominated in kWh, indicative of the power required by the tenant to power their IT load. Physical space is allocated primarily with an eye toward ensuring that no tenant overwhelms the available cooling for the portion of the facility they occupy. While space is incredibly important within a data center, power is more important, as that is the key determinant of the level of computing one is capable of achieving. For tenants engaged in lower-power computing such as routing or storage, space is a more important factor for which they pay in addition to the power they consume.

The Northeast quadrant therefore shows power available on the X-axis denominated in kWh and market rents on the Y-axis denominated in \$/kWh. The corresponding market equilibrium point between these two axes is tangential to the demand curve, as it would be in the conventional DiPasquale/Wheaton model.

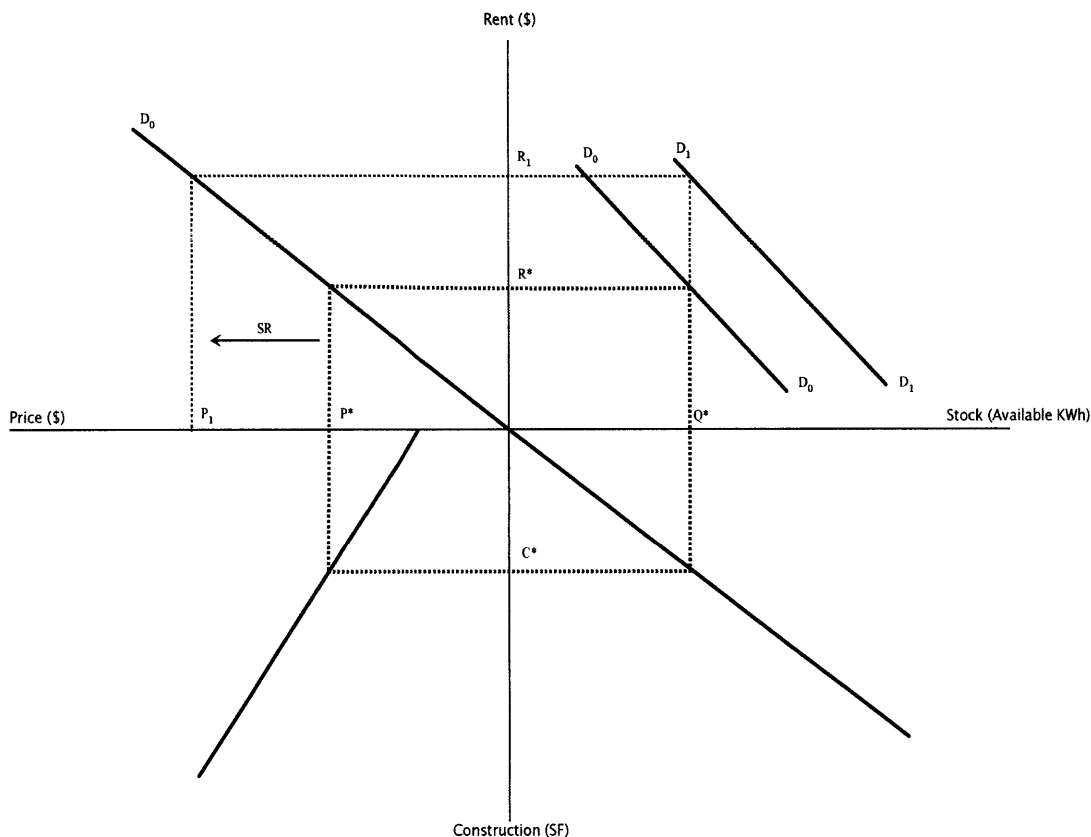
The Northwest quadrant of this graph shows the coordination of rents and asset market prices for data centers. This is largely the same quadrant that one would expect from the DiPasquale/Wheaton model, except that the rents are denominated in \$/kWh rather than \$/SF. Still, those rents are then converted into conventional asset market prices denominated in dollars. The line radiating from the origin outwards would still be a cap rate/yield ratio that would determine the value of the property as determined by rents. In this manner, the northwest quadrant is nearly identical to a conventional 4-quadrant model.

The Southwest quadrant is again very similar to the conventional model. Whether or not the x-axis is denominated in \$/SF or \$/kWh, the idea is the same in that it denominates the price of the asset per unit of product volume. The construction axis (Y-axis) is the same, denominated in SF.<sup>25</sup> The line radiating from the origin is the same, showing the ratio between asset prices and the annual amount of new product being produced in the asset class. It's worth noting that if this sector were to be denominated in kWh, the yield between the two axes and the resulting asset market price would be the same.

The Southeastern quadrant is one of the more interesting in the revised graph in that it shows the "space/power" correction that needs to be made annually. This is denominated in SF on the y-axis and kWh in the x-axis. This makes the line that radiates from the origin a ratio between space and power, effectively tracing the power density of space. This is helpful in that power density is the key marker of the desirability of data center space, making data center space with low available power density undesirable and most likely to be either decommissioned or upgraded to deliver more power. For an example, a facility that was once built for telecom use in the 1980s may easily have been configured for a comparably paltry 5 Watts/SF of power throughout the whole building. This would have been more than adequate for telecom equipment in that period, but not sufficient for a more modern tenant seeking a facility that offers power and cooling infrastructure capable of maintaining 80 Watts/SF (a more common requirement range). The low-power-density (5 Watt/SF) facility would be found to be functionally deficient in today's marketplace, which requires higher power densities amongst other technological improvements such as more robust UPS systems and carrier neutrality. This is the phenomenon being described in the Southeastern quadrant. Now let us examine what happens in this four-quadrant model when demand increases.

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<sup>25</sup> The author deliberated over whether to set this axis in area units (SF or SM) or to denominate the Construction axis in kWh (or MWh), as the brokerage community typically measures incoming supply. The functional advantage to setting the Construction axis in SF is that the product of the Construction and Stock axes is then measured in kWh/SF, a typical power density metric.



Source: Adapted from Geltner, Clayton, Miller and Eichholtz, 2013

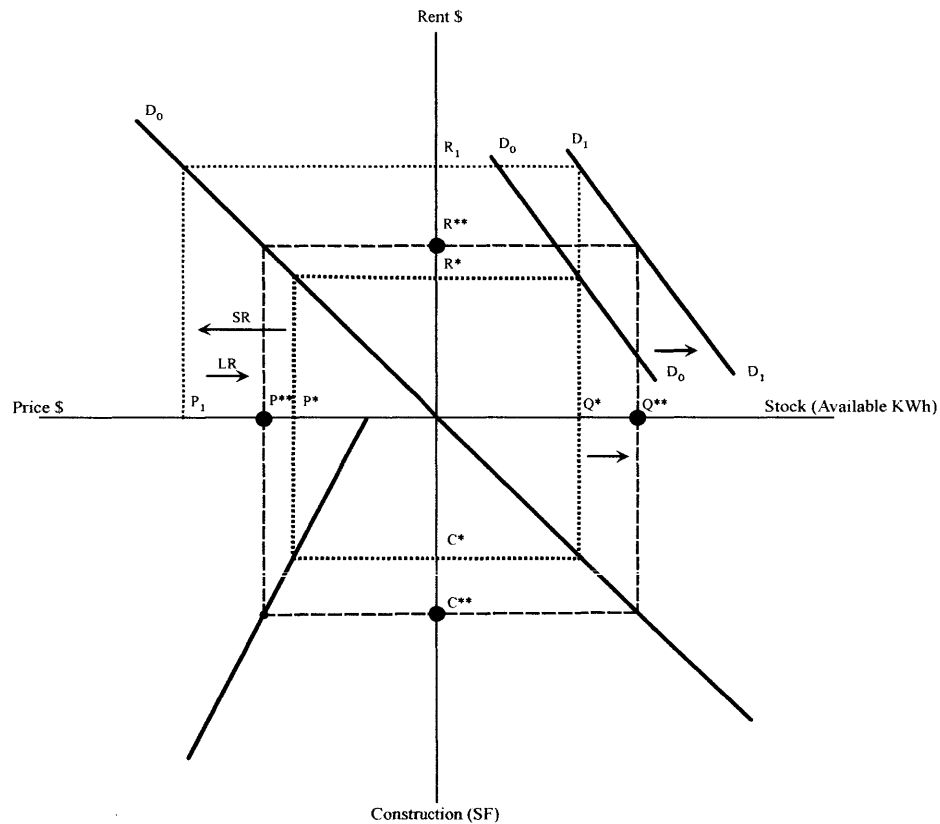
Figure 10: The short-run effects of a rise in demand for data center capacity.

Figure 10 demonstrates the short-run changes after the demand for data center space increases and prices rise. Such an increase in rents can come from a number of causes such as an increase in the number of potential tenants seeking space in data center facilities or any number of other exogenous variables that could affect the desirability of presence in a data center. There is also the possibility of a rent increase because of existing data center stock being made obsolete through changing technological requirements, however since this graph appears to assume a constant stock in the short run, let us assume the demand spike is due to another factor. The demand curve's increase translates into higher rents charged for data center space and power, as more market entrants are competing for presence in a finite number of facilities in a given market, which in turn translates to fatter operating margins for these facilities and more profitable data centers.

This raises asset prices in quadrant two (the asset market), assuming that the asset market values the higher rents and margins of these facilities as they would any other income stream. In the short run, we can assume that that asset market's prevailing capitalization rate for a data center would not change

substantially, and therefore the increase in rents visible earlier would predictably yield a higher asset price on the open market. This would trigger the development of more data center facilities. However, as development takes a comparably long time, the increase in asset prices is the end of the short-run effects.

In the long run, the abrupt rise in asset prices would spur development of more data center space, which is what we observe in the next graph (Figure 11).



Source: Adapted from Geltner, Clayton, Miller and Eichholtz, 2013

Figure 11: The long-run implications of demand and rent increases. Note that the system equilibrates after construction of new space.

Figure 11 shows us the long-run consequences of the abrupt increase in asset prices. In the Southeastern quadrant (construction quadrant) we see an increase in data center space construction, the two axes of which suggests that the threshold of new construction would be measured in Dollars/SF. The uptick in construction of data center space would eventually increase data center stock availability. This brings us to quadrant four, which concerns itself primarily with the obsolescence of existing data center space. The units of the respective axes that define the quadrant are area (SF) and power (kWh), suggesting that the

product of the two would be the threshold of obsolescence for the local market. This makes sense; whereas obsolescence in other real estate product types may be determined by clear heights or energy efficiency or location, the typical means of rating a data center are the facility's power rating on a per-square-foot basis, followed by other factors such as power efficiency (PUE) and bandwidth concerns. This quadrant shows how rising power requirements for computer hardware makes older, less power-dense facilities obsolete. Figure 11 shows us the whole cycle competed and re-equilibrated, where a marginal increase in the amount of available data center space in turn brings rents back to equilibrium levels and lowers asset prices to a point where additional data center construction is no longer necessary. This is remarkably similar to the process originally outlined by DiPasquale and Wheaton and later reiterated by Geltner, Clayton, Miller and Eichholtz.

## Chapter 8: Demand Indicators

Data center space demand is notoriously tricky to predict. No research has yet found a means of predicting market demand or even defined the boundaries of data center markets. This is burdensome because the high cost of developing these facilities means that potential investors in such a venture require assurance that the project will not lie fallow.

Allegorical evidence and broker research points to many different factors determining the ultimate decisions on the part of firms to locate in a given market. The most prominent of these reasons include tax burden of the target market, infrastructure, cost of electrical power, the proximity and quantity of available fiber, and the costs of construction and land (CBRE Data Center Solutions, CBRE Research, Q3 2015). While total cost of ownership calculations factor prominently in these decisions, they do not explain the market entirely. While these considerations are prominent factors in the creation of data center agglomeration hubs such as Atlanta, Quincy and Charlotte, they do not explain the presence of much larger agglomeration hubs such as Silicon Valley, Dallas or Northern New Jersey, where the density of firms requiring large data center presence overrides other cost considerations (Tranos, Nijkamp 2013). Furthermore, the infrastructure of the growing Internet has not been closely mapping the population distribution of the United States and has been developing its own topography more closely linked to transoceanic cable systems and hub cities that can connect to the most valuable domestic and international fiber routes (Malecki 2001). Rather, research would suggest that the development of broadband Internet triggers greater economic growth and draws population thereto (Czernich, Falck et al., 2011). How, then can we predict demand for data center space?

One means of predicting the desirability of a given region of the United States for data center activity is to look for transcontinental cable landings. While exact information regarding the whereabouts of this infrastructure is necessarily sensitive, the general location of this infrastructure is widely available, and free of charge.<sup>26</sup> Submarine cable landings tend to be located in areas that have historically had telephone infrastructure and areas that have easy access to the widest number of people. Further considerations such as the bathymetry of the ocean floor and a given route's proximity to destructive ships' anchors or turbidity currents also play a role. These fiber optic rights of way are seen as increasingly important national resources that must be protected accordingly, so routes are frequently chosen to minimize the chances of interference by malign state-sponsored actors (Sanger, Schmitt 2015). Increasingly, fiber optic cable landfalls are becoming the 21<sup>st</sup> century's status symbol, redolent of the deep water ports of centuries past.

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<sup>26</sup> Websites such as TeleGeography's [submarinecablemap.com](http://submarinecablemap.com) freely offer updated information regarding cable landings, approximated routes and bandwidths. What is notably missing, however, are specifics of the submarine cable routes. National security considerations are often invoked when protecting oceanic fiber optic resources.

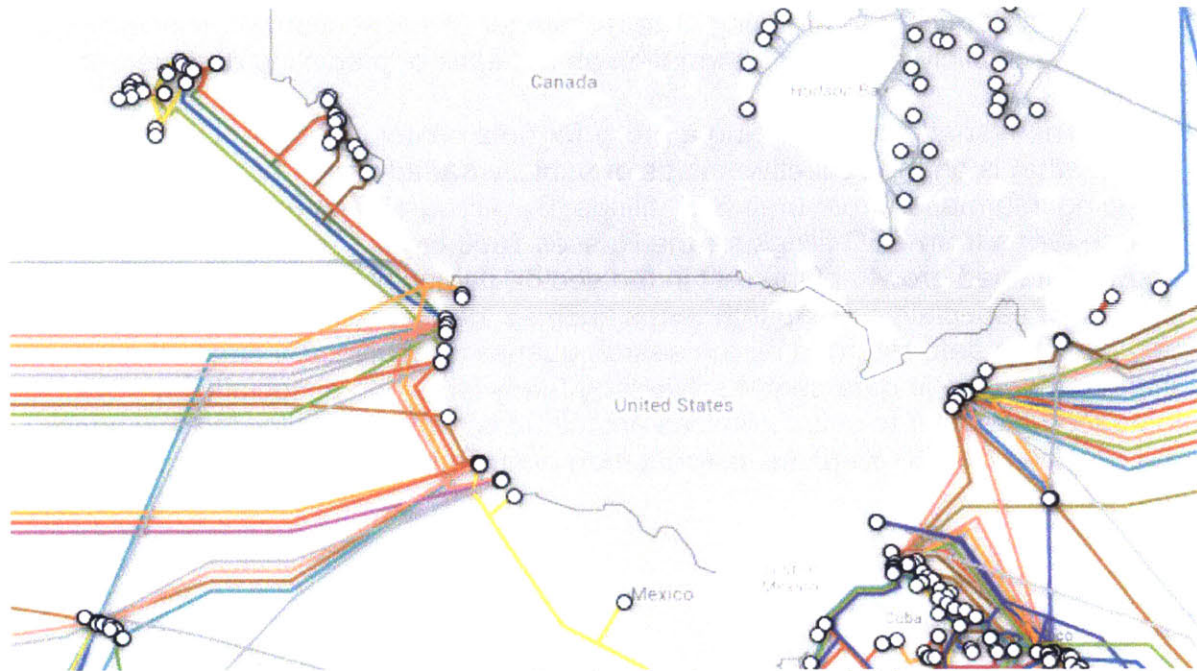


Figure 12: Transoceanic fiber optic cable landing sites for the continental United States and environs, courtesy of TeleGeography website submarinecablemap.com

As these fiber routes make landfall, data center facilities are required in order to interpret, route, store and process information as it comes ashore. This is not a new phenomenon (Blum 2012, pg. 191), and it leads to an agglomeration effect near where these cables come ashore and join into the national fiber optic grid.

Once on land, data center location is driven more by economic, political and geographic considerations as much as they are the laws of physics. The speed of fiber optic data transmission means that firms seeking to locate their IT infrastructure with less than a five-to-ten-millisecond latency could comfortably do so in an area with a radius of roughly 500 miles.<sup>27</sup> In this manner, the 'data center market' for the United States is really a national market with submarkets roughly the same size as a given time zone. Ancillary considerations such as construction cost, land cost, power costs and tax burden are the deciding factors for where to site a facility.

A more difficult task would be to parse out what the likely demand for data center capacity will be in the near future. An extensive literature review and dozens of conversations over the past year suggest that there is no forecasting mechanism in place yet that attempts to quantify the amount of short term data center capacity. For a comparably new field, very little data exists yet that might help in this endeavor. Fortunately, some information regarding the general interest of firms in data center technologies and services may act as an early

<sup>27</sup> This is more a function of the effective path of the fiber versus a geographic radius. The signal latency would largely be a function of the network's topography rather than geographical distance. Sheputis had offered his opinion that the agglomeration points we see throughout the country are largely separated by 5 to 10 milliseconds on the network and that was the driving force behind these markets' staying power.

indicator of data center spending. The remainder of this section will concern itself with using publicly-available information as a means of predicting data center demand.

The first attempt at finding a proxy for data center investment was to gather what is on the collective minds of publicly-traded firms from 2000-2014 by scraping information from their SEC filings. By pulling all incidences of selected search terms from SEC filings for the Russell 2000 Index,<sup>28</sup> patterns emerge that show sustained growth of interest in the sector, particularly in the last seven years and especially with search terms such as “data center”, “cloud” and “cloud service”. The data returned by the search queries unequivocally suggest a marked increase in data center interest by many firms and especially an increased attention to cloud services and cloud activity. The following few pages will be given over to graphical presentation of findings followed by interpretation of the data.

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<sup>28</sup> Method involved using an open-source web crawling framework written in Python. The algorithm then crawled through all SEC filings using each firm’s CIK number. The number of firms targeted was limited to the Russell 2000, as the sample size seemed perfectly adequate to gather sufficient data for recognizable patterns to emerge.



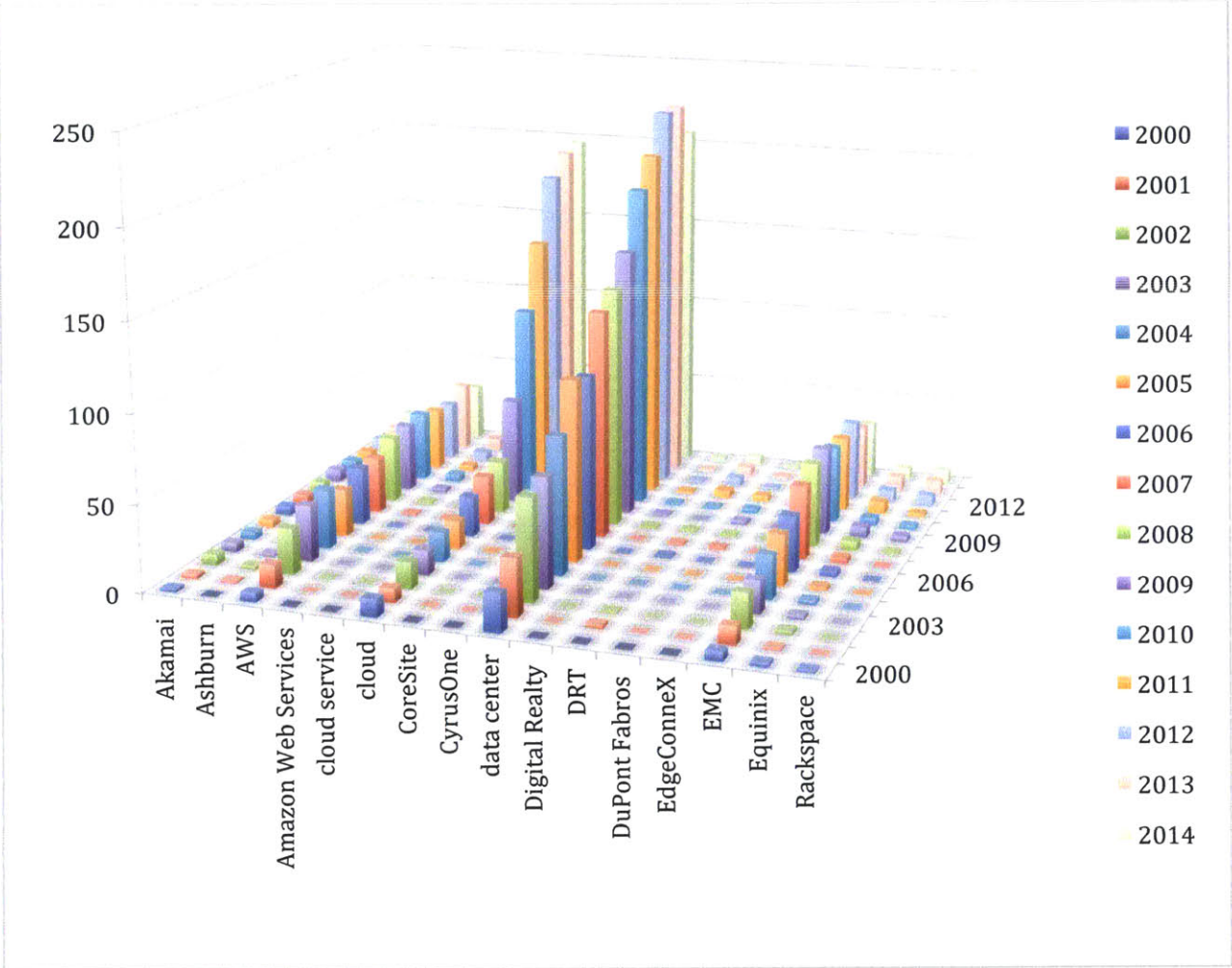


Figure 13: Graph of search term incidences and their respective years 2000-2014.

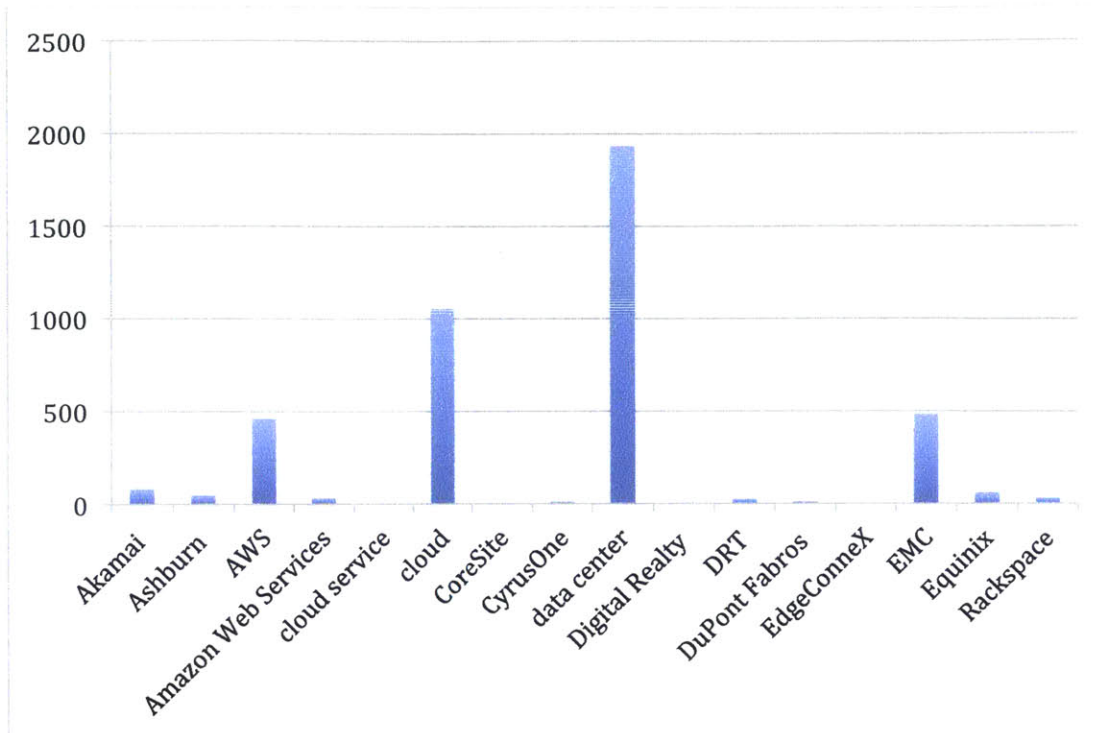


Figure 14: Similar graph of search term incidence, irrespective of chronology, 2000-2014.

### Incidence of the Search Term 'Data Center'

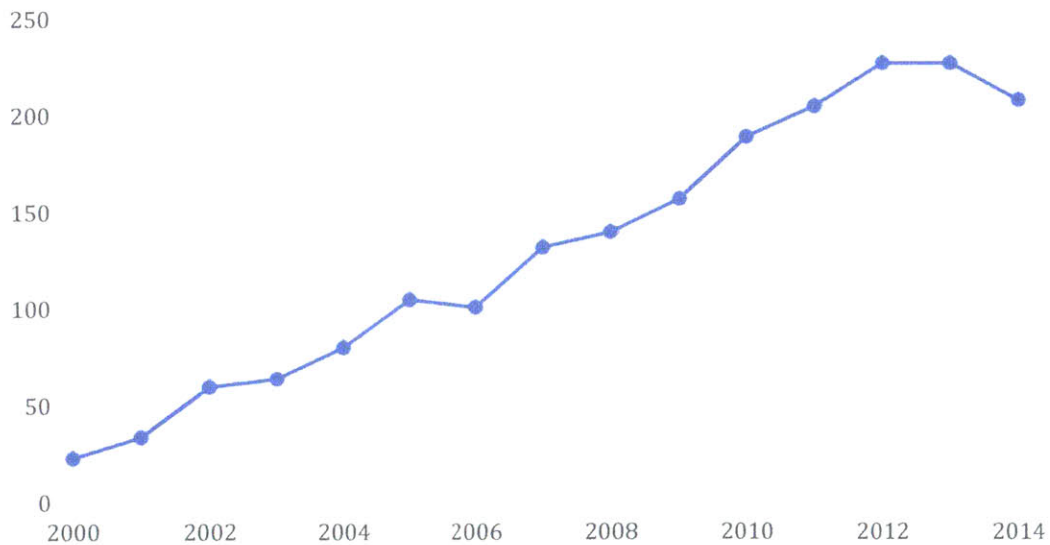


Figure 15: Incidences of the search term "data center", 2000-2014

### Relative Incidence of "Cloud" vs. "Cloud Service"

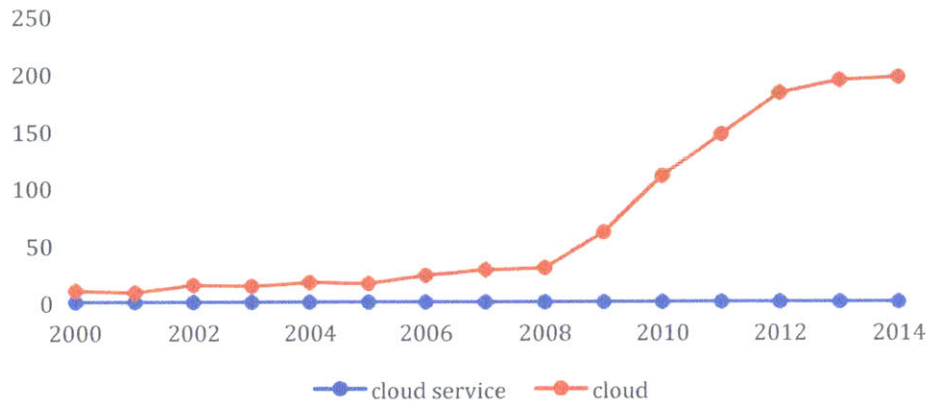


Figure 16: Comparative incidence of the search terms "cloud service" and "cloud", 2000-2014

### Incidence of the Search Term "Ashburn"

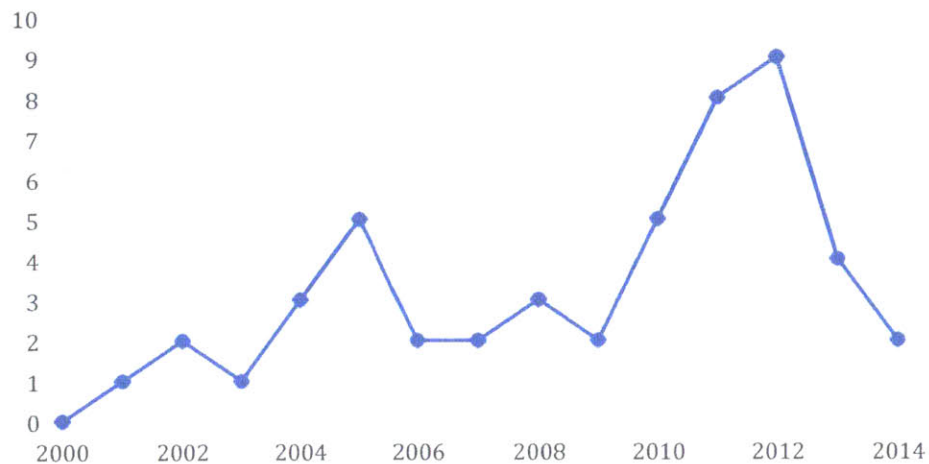


Figure 17: Incidences of the search term "Ashburn", 2000-2014.

The immediate and most obvious conclusion of the data is the surprisingly high incidence rate of the term "data center" over others, including the term "cloud". What is more surprising to the author was the decline of popularity of "data center" and the rise of "cloud" at a faster rate. This could suggest either the declining appeal to firms of owning their own data center facilities, or perhaps the changing landscape of IT buzzwords. In examining these data, patterns emerge that may be of use for investors. The best example of this would be in studying the incidences of the search term "Ashburn", wherein mentions peaked in 2013 and sharply dropped off thereafter. The low incidence rate (9 peak mentions)

show that it was likely either one firm repeatedly mentioning Ashburn or several giving only one mention, and then dropping the subject in subsequent reports. Regardless, this would be a useful tool if scaled up for mention in other markets such as Quincy, Hillsboro or North Carolina when paired with “data center” to sniff for possible development activity.

Another discovery is the rise of the popularity of the word “cloud” (Figure 16), which appears to be levelling off even as the use of “data center” is marginally diminishing (Figure 15). This may suggest that either both terms were buzzwords or that corporate investment in both has been slowing. The incidence of both search terms at the moment would suggest that the rapid growth in popularity for these search terms over the past dozen years is coming to a plateau, and with it additional development activity. If a link between corporate attention to data center development activity or cloud investment and actual data center capacity demand surge can be proven, this method of determining data center demand may prove to be a more responsive proxy for the health of the data center market.

The information coming from these SEC filings seems more relevant to gauging overall market interest and general trends than it is to predicting market behavior. A more solid approach to researching corporate investment in data center research and development would be to quantify national and international patent activity relevant to the field.

Patent activity is easier to follow.<sup>29</sup> By searching for the top three search terms (data center, cloud and cloud service) by year, we discover some very pronounced terms that follow similar patterns as the search through corporate SEC filings. The methodology of this search involved simple patent searches done in all languages and nationalities. The same searches were also conducted on US-only, English-only patents settings and yielded the same results.

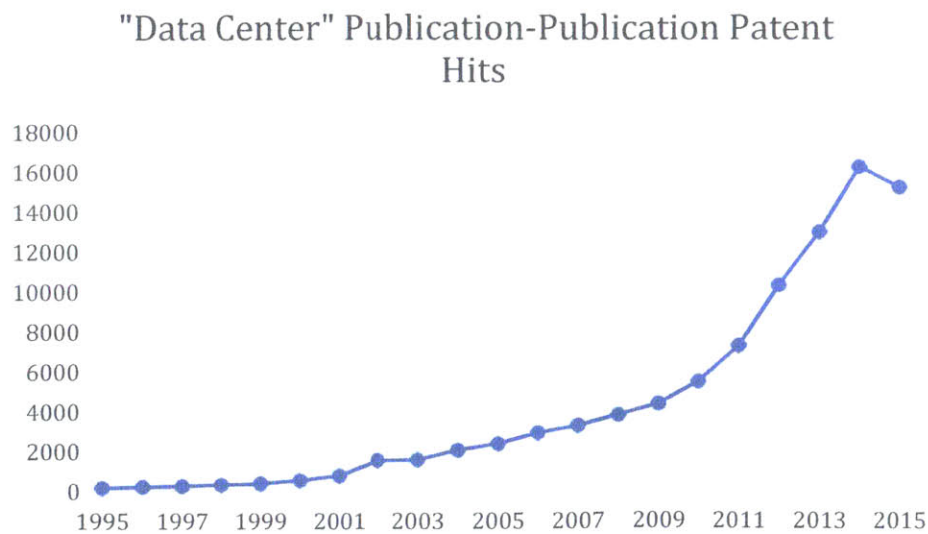


Figure 18: Patent-search incidences of the term "data center", 1995-2015.

<sup>29</sup> Google's Patent search functionality requires little setup and is updated constantly.



The marked increase in patent filings including the term “data center” is visible in this data, as it was in the SEC filing data. In this case, the search methodology allowed us to use a longer history (back to 1995 rather than 2000) and yielded a similar result, showing drastic increases in activity after 2000. The decrease of incidence may correspond to the similar decrease noted in the SEC search data or may be indicative of lag in the patent filing data.

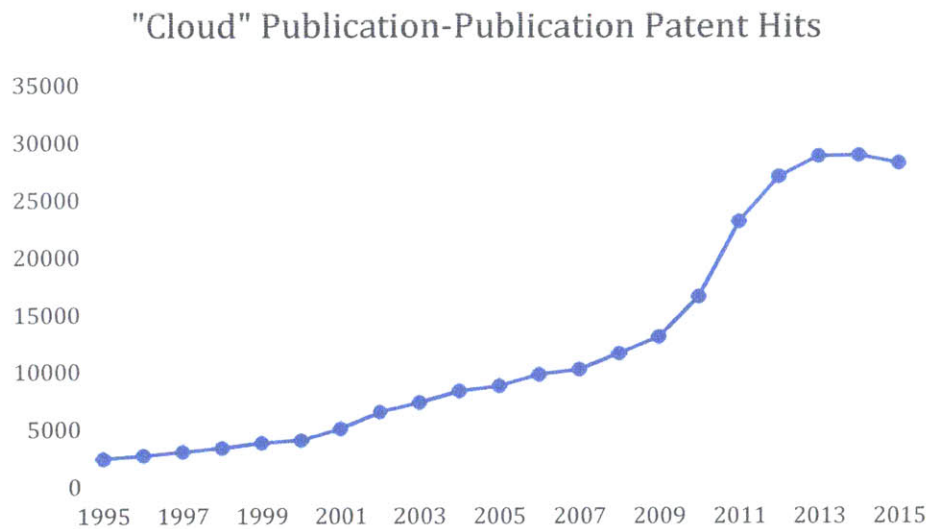


Figure 19: Patent-search incidences of the term "cloud", 1995-2015.

The trend visible in the “data center” patent data is on display in the “cloud” data (Figure 19) as well; sharp increases in incidence after 2000 or so, yet the incidence rate would appear to be decreasing after the year 2013. This would correspond to the marginal decrease we saw in the SEC data of the instances of the term “cloud”. This finding reinforces the possibility that we are witnessing a decrease in corporate R&D spending on both data center and cloud activity, and that a corresponding decrease in data center and cloud capacity demand may be in the horizon.

## "Cloud Service" Publication-Publication Patent Hits

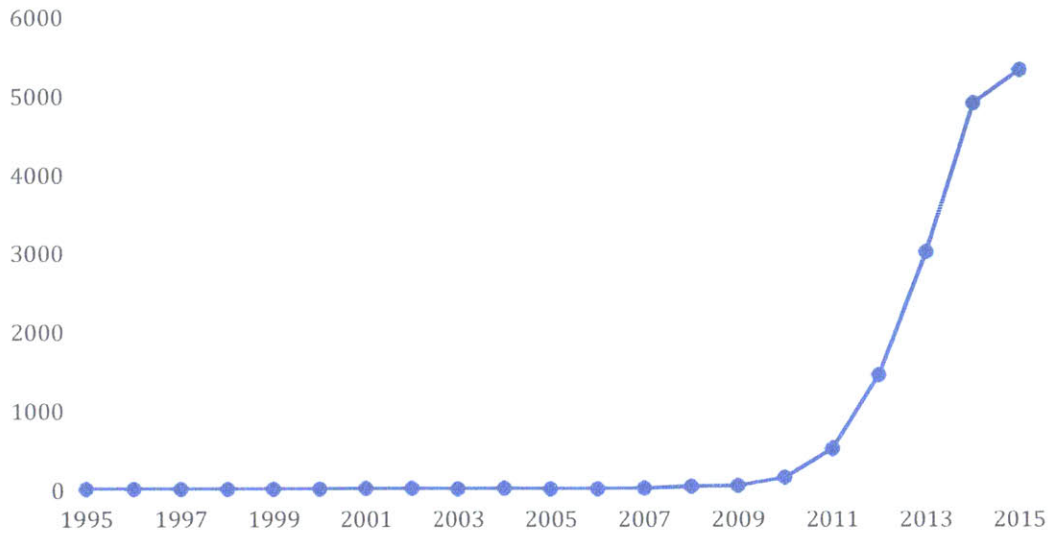


Figure 20: Patent search incidence of the term "cloud service", 1995-2015.

The "Cloud Service" graph (Figure 20) is the most interesting of the bunch. The graph shows a steep climb in the incidence of "cloud service" in patent filings, but these data do not correlate to what we've seen in the SEC data, where incidence of "cloud service" was virtually nonexistent. Here we see steep increases in incidence after 2010 and perhaps the beginning of a plateau in incidence rate. In any event, the lack of any correlation between the two sources (SEC and Patent) of information on corporate R&D activities suggest that while data center and cloud investment are prominent focuses of IT spending, cloud services may still only be the focus of investment for startups and speculative patent-filing entities rather than the sustained subject of focus by firms in the Russell 2000.

The data suggest a conclusion that data center and cloud investment by publicly traded firms appears to be following a similar pattern of activity in patent filings and that both trends suggest a moderate decrease in R&D activities that may take time to manifest itself in the data center space market. If this finding proves accurate in the medium-to-long-run, similar data mining techniques should be used to gauge the health of the data center space market in future development cycles and investment capital can make more educated investment decisions.

## Chapter 9: Supply

Internet infrastructure is a new product type in real estate, and certainly the least understood of any major real estate investment product. Any discussion on data center supply should be informed by a comprehensive list of all data center facilities in the area being studied and an equally deep understanding of these facilities' power characteristics and service levels. This is where the trail runs cold, and presumably the reason so few researchers have studied this new product type: lack of decent information. Other than a powerful effort on the part of Chegut mentioned earlier, few researchers have ventured into these waters or even accumulated sufficient data to assess the asset-market performance characteristics of these facilities. The lack of available information for Internet infrastructure as an asset class, unlike that which is available to other asset classes such as Hospitality or Office, is a major impediment to the sector's widespread adoption by the investment community.

The previous chapter's efforts at measuring demand by looking at search-term hits and patent filings was an attempt to find a proxy at overall data center demand. This chapter will seek to do the same by mining the few sources of information available to the author, both publicly and privately, for correlations that would show patterns of data center development throughout the US.

Any study of data centers should attempt to answer questions surrounding optimal placement strategies. For lack of any available data regarding power or service levels, the variables I opted to examine were each data center facility's proximity to transmission power lines, fiber optic cable, railroad lines and other Internet exchange facilities. All these variables were easily obtained either from government or third party sources as GIS data packages or taken as downloads from websites. In the case of the fiber optic data, we had to improvise for lack of a nationwide fiber map. Instead, the US Census Bureau's broadband speed information package, broken down by census block and categorized by carrier, service type and upload/download speed functioned as a reasonable proxy for the presence of fiber optic service.<sup>30</sup> We were able to plot all these data in GIS and get maps and distances from the resulting composite. The maps themselves

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<sup>30</sup> Though this method may be crude, it gave us reasonable resolution with which to ascertain the presence of large amounts of fiber at the census-block level, which in turn gave a reasonable idea as to the relative presence or absence of fiber optic infrastructure in rural and suburban areas of the US. The data package was 7.3 GB in total, and much more information can be gleaned from its contents. We simply extracted all fiber-enabled census blocks and spread them over a map of the US. This map is primarily a measure of residential service, so there are atypical areas where commercial fiber is obviously present but residential fiber is unavailable, such as Boston, MA. This may be an indication of the 'last mile' problem where service is present but the cost of running it to residences is prohibitive.

are a busy mess of overlaid data points and lines:

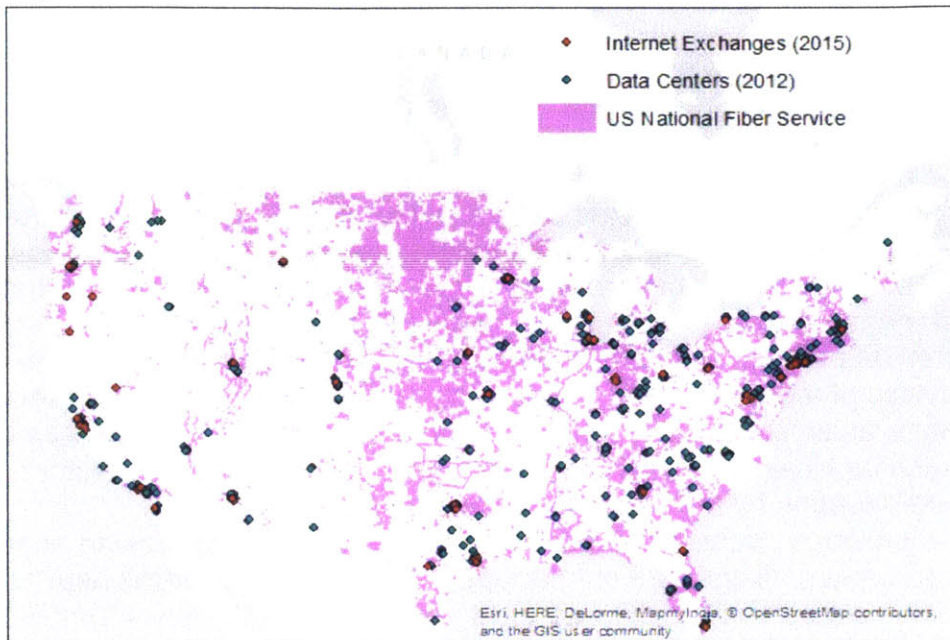


Figure 21: Fiber optic service zones mapped with data centers (green) and Internet exchanges (red)

Figure 21 is a visual synopsis of the fiber data that was culled from the US Census broadband data. The lavender portions of the map show census blocks that are replete with fiber optic service and hence would offer relatively easy access to fiber optic infrastructure for any data center near these zones. The green dots are the 1,150 data centers provided for the year 2013 by datacentermap.com. Finally, the red dots are the Internet exchanges that form the backbone of the routing structure of the US Internet. There is a high correlation between these three entities and this relationship will be examined in greater depth further on.



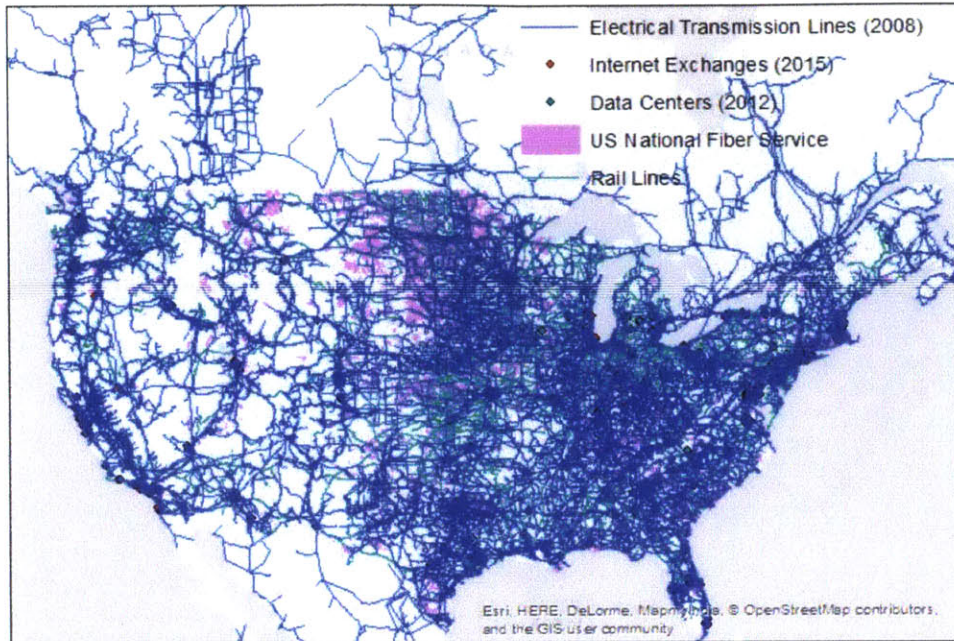


Figure 22: All the GIS maps put onto one composite map.

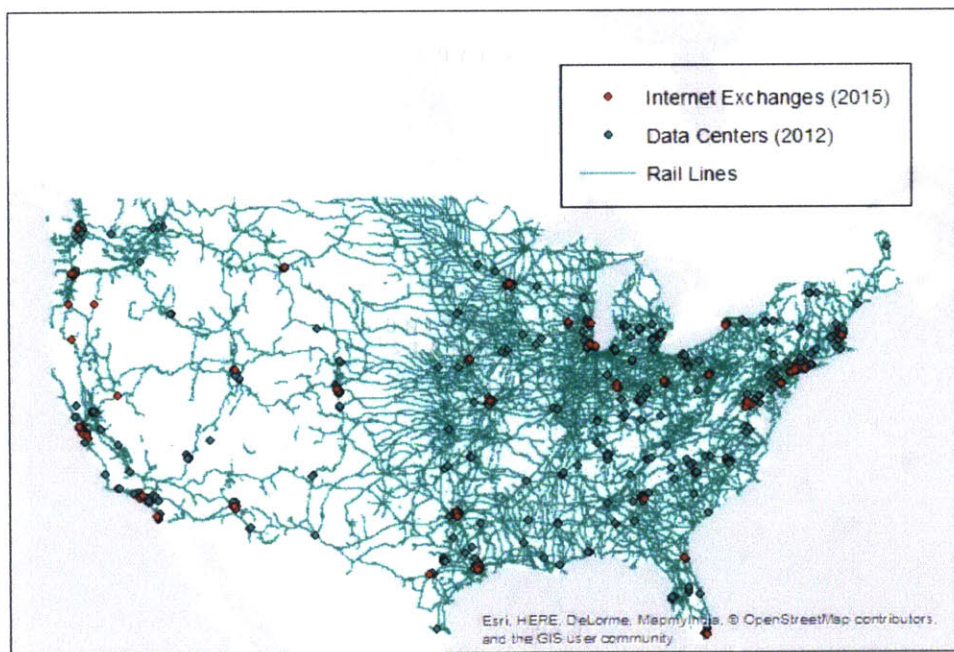


Figure 23: The US railroad network, mapped with data centers and Internet exchanges.

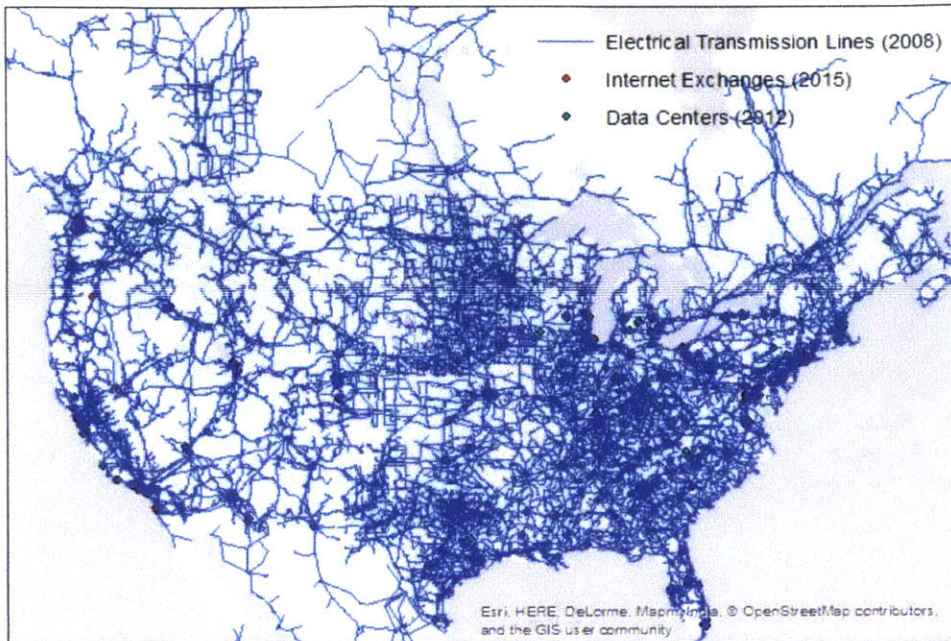


Figure 24: The US network of power transmission lines, mapped with data centers and Internet exchanges.

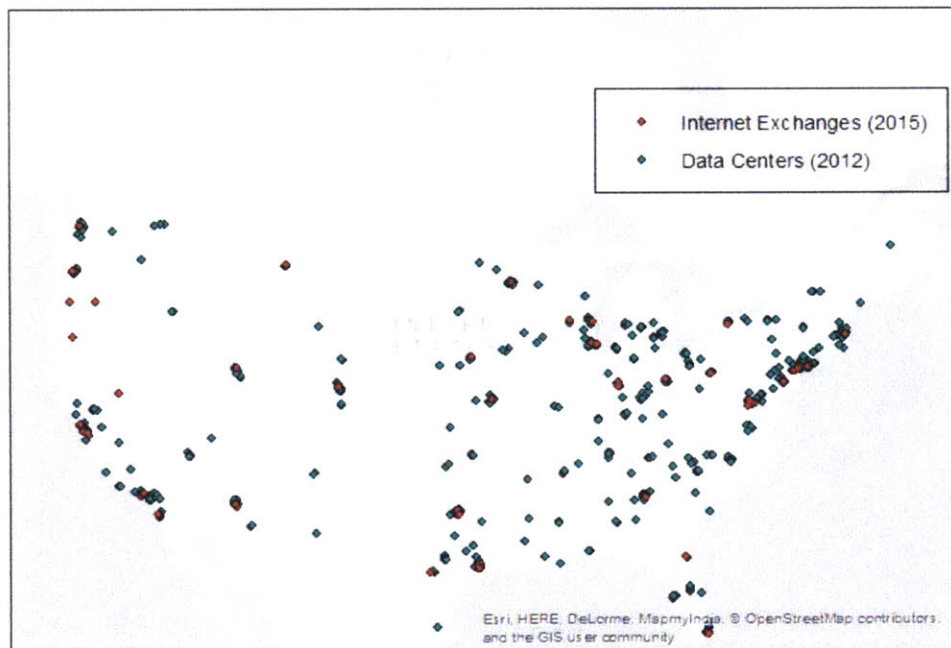


Figure 25: For the sake of comparison, a simple map of data centers (in green) and Internet exchanges (in red).

These maps may not reveal a great deal of new information at first glance, but are an interesting means of glimpsing the correlations between each of the variables, particularly as the population thins out going from the East coast of the



US to the West. The map of data centers (green points) and Internet exchanges (red points) in Figure 25 is among the most simple and revealing; it shows there are a great deal more data centers than Internet exchanges and that exchange points need to be in population centers around which data centers cluster. Figure 24, which examines power transmission lines and data center locations, shows the extent to which electrical transmission infrastructure is developed throughout North America and the approximate location of data center and Internet exchange facilities are located. The comparably low resolution of the map demonstrates that any useful correlations between these variables will best be shown numerically rather than graphically. Figure 23 shows the unsurprising relationship between Internet infrastructure facilities and railroads, both of which exist to connect cities and people with each other and hence will cluster together around cities. Again, the more interesting information to come from these variables will best be viewed numerically rather than graphically. Figure 22 is possibly the most interesting of the bunch, in that it shows that high correlation of all variables to one another, with the exception of the large fiber-enabled census blocks that cover much of the northern central US. Each of these maps is interesting, but the information culled from their GIS underpinnings is more so.

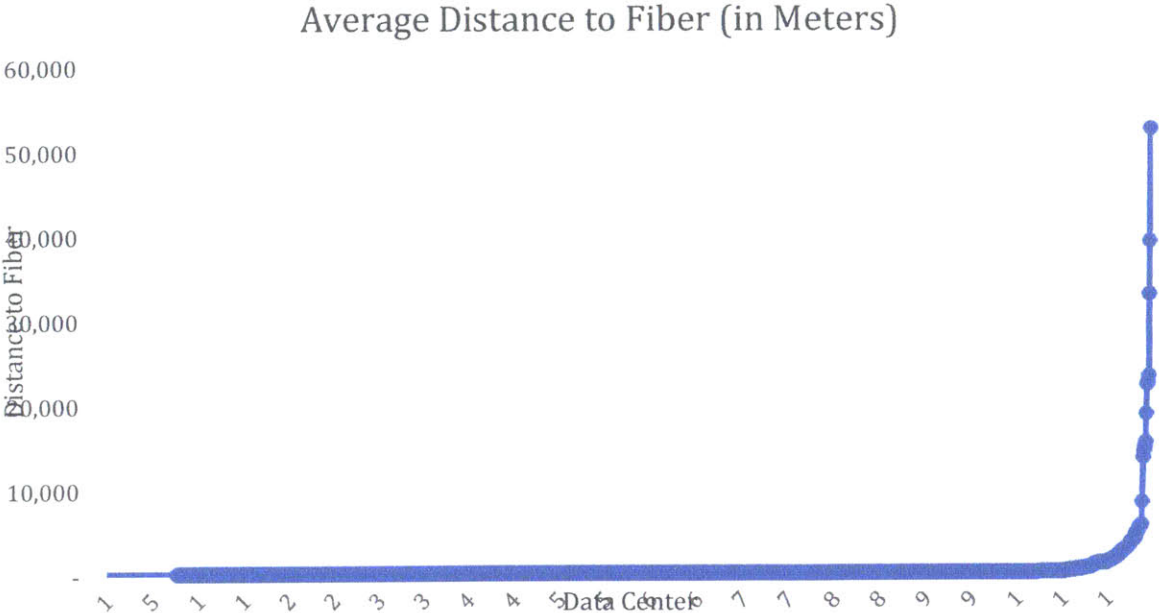


Figure 26: Graph of the distances (in meters) to the closest Census block with fiber optic cable.

The GIS analysis portion of this inquiry focused on distance relationships between the variables (Internet exchanges, transmission lines, railroads and fiber optic-enabled census blocks) and each of the 1,150 data centers in the data set. Unsurprisingly, each of the variables showed close proximity, on average, to the data centers. Figure 26 is particularly illustrative of this: almost all the data centers in this study in the US are either inside fiber-enabled census blocks or

are remarkably close. This proved to be a strong correlation; more so than with any of the other variables explored.

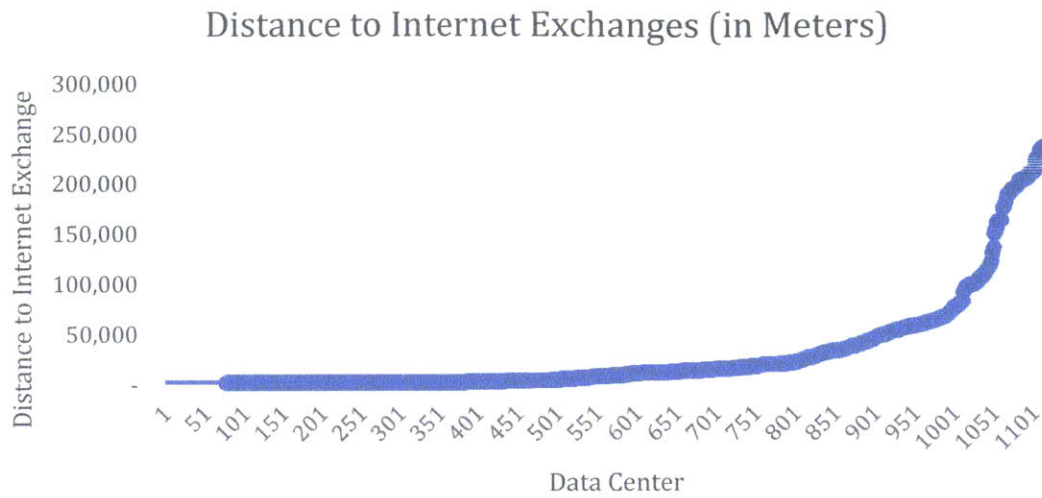


Figure 27: The distances to the closest Internet exchange for each given data center.

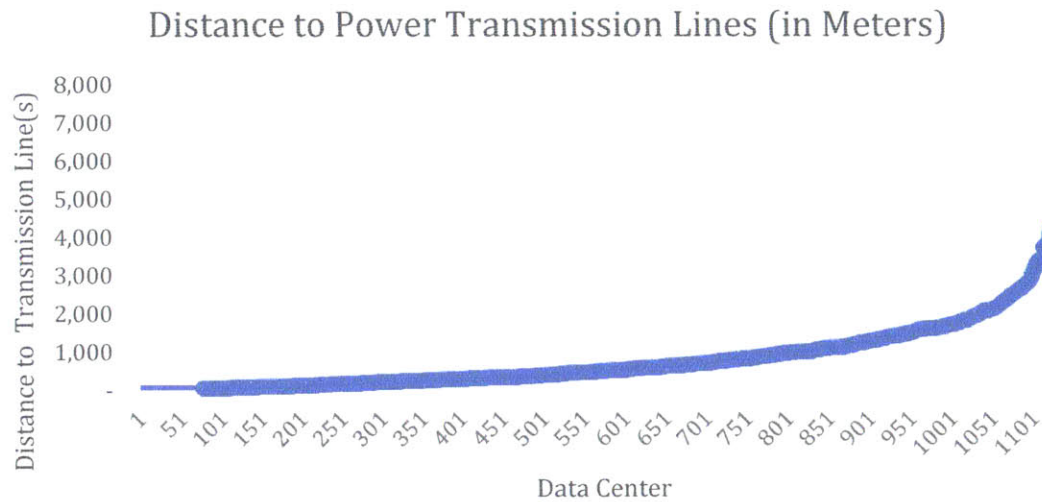


Figure 28: The distance to the closest power transmission lines for each given data center.

Other variables such as the distance(s) to power transmission lines or the closest Internet exchange showed similar patterns as with distance to fiber service, however the relationships are not quite as strongly pronounced. Whereas the curve describing the distance to the closest transmission line appears to be asymptotical, the curve sketched for Internet exchange proximity appears far lumpier, possibly as a result of the far smaller number of Internet exchanges in the US than the number of transmission lines. In the distance to the

closest railroad graph (Fig. 29), we see largely the same graph as we saw in Figure 28, with asymptotical growth and well more than half the observations measuring in at under 100 meters between a data center and the variable being observed. In all these cases we can see the same trend in the data, but different aspects of the distribution(s). We will examine these relationships in greater depth using non graphical means.

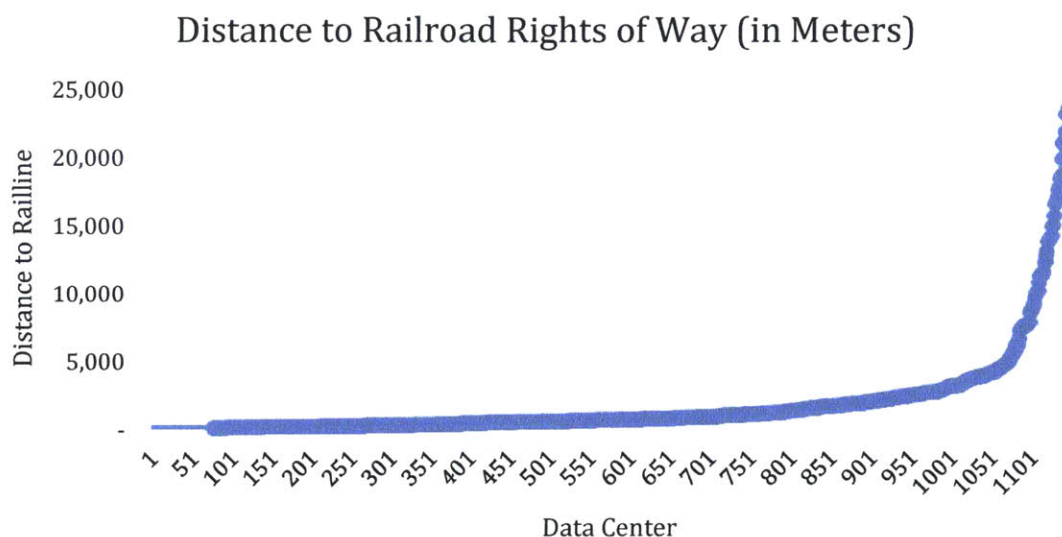


Figure 29: The distance to a railroad for each given data center in the data set.

All these data are interesting visually, but the real power of using GIS is the strength of the analytics tools available for statistical approaches to these data. In the interest of simplicity, the GIS output data were only analyzed for mean, standard deviation, minimum, maximum, skewness and kurtosis.<sup>31</sup> Nevertheless, pronounced trends are visible. The mean distance from any of the data centers to an Internet exchange was by far the highest and the mean distance was clearly the lowest to a fiber-enabled census block. This is most likely a function of the low number of Internet exchanges and the high incidence of fiber-enabled census blocks. The relatively low mean distance to a transmission line versus a railroad was also somewhat surprising; the author had gone into this analysis expecting that railroads would be more central to data center placement and success than transmission lines given that railroad rights of way are commonly used as fiber conduits across the US.

<sup>31</sup> One curious inclusion in each data set was that the two highest returns in each distance category (distance to fiber, railroads, etc.) were inevitably either twice the next highest number for sometimes an order of magnitude higher. As a result, we trimmed out the top two highest distances for each data set.



Distance to _____ (km)	Mean Distance (km)	StDev Distance (km)	Min (km)	Max (km)	Skewness	Kurtosis
Internet Exchanges	33.5842	60.7896	- 0.0010	283.2787	2.37	4.67
Transmission Lines	0.8025	1.0270	- 0.0010	7.0281	2.59	8.55
Railroads	1.6250	3.2291	- 0.0010	23.5235	4.08	18.98
Fiber (Census Block)	0.2930	1.9174	- 0.0010	32.8494	10.87	137.42

Figure 30: Table of analyses of each GIS variable, focusing on Mean, Standard Deviation, Minimum, Maximum, Skewness and Kurtosis.

This finding would indicate that while that may be the case, proximity to transmission lines either offers marginal utility gains to data center customers and developers or simply that transmission lines are surprisingly common and hence unavoidable. We will revisit the relative ubiquity of railroads versus transmission lines later when we examine skewness and kurtosis for both distributions.

The standard deviations of these data show that data centers tend to be a fair distance from an Internet exchange and that of all the necessities of a successful data center, proximity to an Internet exchange is not the highest priority. The standard deviation for distances from a data center to an Internet exchange was a sizable 60,790 meters (~60.8 km). From this we can establish that proximity to an Internet exchange is not as high a priority as proximity to power or fiber. It is worth noting that the ~60 km standard deviation is far lower than it needs to be, as the marginal difference in time between a signal travelling 60 km and 1km is so small as not to matter. This is relevant in that data centers are not required to be so proximate to Internet exchanges; they could easily be several hundred miles away with no discernable increase in latency. The fact that the maximum distance to an Internet exchange is so low suggests that This finding may be a reasonable proxy for data center proximity to a large city, where one would be more likely to find trained technicians that are able to design, service and operate a data center. It is also worth noting that the mean distance to an Internet exchange is ~33.5 km, meaning that quite a few data center facilities opt to be some distance from an Internet exchange, suggesting that either the price of land, access to power or access to fiber is far easier (and cheaper) the further one travels from a city that contains an Internet exchange.

The standard deviation statistics for railroads, fiber and transmission lines are similarly interesting. All these standard deviations were higher than their means but the railroad standard deviation for distance was over twice its mean, suggesting that a comparably small number of outliers are influencing the data. In all, these three variables echo what we've seen on their graphs, that most data centers in the US are very close to each of these variables, and that a minority of facilities are not close.

The minimum and maximum data are a mixed bag in that the maximum data is very valuable (giving an indication of the range of values one can expect) and the minimum data are all exactly the same at one meter. In this case we see that the maximum distance to an Internet exchange is ~283 km, a lower sum

than the author would have imagined.<sup>32</sup> This again underscores that proximity to an Internet exchange is important to customers and that they still measure the distance from a data center to an Internet exchange in kilometers rather than milliseconds. Whether this is because of infrastructural benefits, better access to power and fiber, the availability of a skilled workforce or good old-fashioned server-hugging is another question for further research.

Last of all, the skewness and kurtosis of the four variables are revealing. Skewness and kurtosis are measurements of the shapes of the asymptotical curves for each variable and allow us to see which are the most biased towards the right and which slope up the fastest. All four variables rank in kurtosis and skewness in the same order. All four variables show kurtosis greater than 3, making them leptokurtic, and show overwhelmingly positive skewness. As mentioned earlier, each curve we've examined so far has hewed to roughly the same shape, with some minor variations. The shapes of each curve indicate the relative demand elasticities of the variables being examined, and the proximity to fiber optic infrastructure would appear to be the most desirable input of the bunch, judging by the fiber curve's high rankings in both skewness and kurtosis. The next highest ranking went to railroads (likely a proxy for fiber and/or infrastructural development), then to transmission lines and finally to proximity to Internet exchanges. The skewness and kurtosis rankings verify (in concert) that market forces have deigned that proximity to fiber is the most important feature for anyone looking to locate a new facility, followed by proximity to power and last of all proximity to an Internet exchange. These are somewhat intuitive findings, however they give a more solid footing and basis in fact to the rules of thumb that engineers have developed in the industry. Most importantly, we are making incremental progress in discussing a heretofore shadowy product type about which little has been studied.

One detail that should not be overlooked is the viability of using publicly-available census data in lieu of expensive fiber-optic cable maps. Though the detail of such a method suffers, resolution at that scale is less important when looking at a full map of the US. That the findings of this exercise ended up dovetailing neatly with similar findings both by Chegut and within the exercise itself (fiber and railroads ranking first and second, respectively) should speak to the viability of using census data as a proxy for expensive fiber optic pathway maps.

Another finding of particular consequence from this exercise is the clustering effect we see nationwide around Internet exchanges. Given that fiber optic infrastructure offers incredible speeds, data centers could feasibly be located anywhere within several hundreds of miles with no appreciable increase in latency, yet the GIS data shows that data centers instead cluster within roughly 60 km, and that the largest distance between a data center in our data set and an Internet exchange is roughly 280 km. This is a far smaller distance than expected and suggests that data center clustering is a stronger behavioral trait than

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<sup>32</sup> In fact this number is so low that it calls into question the integrity of the underlying data center data. The cluster of data centers in Quincy, WA would be roughly this distance from downtown Seattle, where the nearest Internet exchanges would be.

dictated by physics. In other words, data center locational decisions appear to be more closely linked to considerations such as infrastructural characteristics and talent pool than land and power pricing. The speed of light is less relevant to data center location decisions than traffic and other development patterns.

There is a great deal left to be studied in data center supply. This study was unable to address any questions that required power information in any of the data centers that comprised the data set that we examined. That being said, we were able to study where data centers tend to be located and infer from that information what inputs are most important to developers and their clientele as they make locational decisions. This is a field that requires a great deal more study as the Internet continues to grow and its characteristics increasingly determine the geography of success and economic growth in the 21<sup>st</sup> Century.



## Chapter 10: Discussion

After several decades, we've figured out that the Internet is really important. It has driven economic progress worldwide for the past several decades and shows no signs of slowing. This is important to the real estate development and investment communities, as the Internet has a physical footprint that has had surprisingly little attention paid to it. If the Internet makes money, its landlords will do the same.

### Summary Findings

Throughout this thesis, we have examined the inner workings of a garden-variety data center, examined the data center market in the US to the extent possible through public records, have addressed concerns about the viability of data center investment in the face of the advance of Moore's Law and cloud computing, examined possible lead indicators of aggregate investment in data centers (R&D, patents and possible leasing activity) and now looked at the drivers of supply (where we locate these facilities and why). Throughout these chapters, the author has endeavored to examine some of the following points:

- Moore's Law is not a threat to data center development, demand or revenue streams. It serves as an inducement to further investment in the field by firms with pronounced IT footprints and pulls more firms into the space. The rapid progress toward faster, more efficient calculation and storage of information allows more firms to enter into a sector whose advances push greater economic advances, from smartphones to data mining, social media services to autonomous cars. As a result, the greatest threat to data center space demand is not the advance of Moore's Law, but that a cessation of these technological advancements would force data center tenants to economize their IT footprints when progress ceases to yield new opportunities for advancement.
- Cloud computing is not a threat to data center demand. Though the continued progress of cloud services may cause a one-time correction to existing data center space demand (as firms use this tool to abandon or refurbish their most energy-inefficient spaces), this is a one-time correction to existing stocks. Furthermore, as cloud services grow in popularity, cloud service providers will become the emergent data center capacity customer. At the end of the day, cloud computing and cloud services are still data center tenants that will pay princely sums for access to power, cooling and bandwidth. This new tenant type may change the market, but they certainly will not destroy it.
- Data center aggregate demand is difficult to predict, but not impossible. The efforts made in this paper will have to be proven over time and reexamined, however the declines in stated interest in data centers, cloud services and cloud computing both in corporate SEC filings and patent filings would suggest that either firms are decreasingly interested in data center space or in R&D investment in data centers and cloud services. This could be a

harbinger of a market correction or simply an indicator that the sector's 15 minutes of fame as a hip investment topic are up. Either way, the trends in the data suggest that stated interest in the sector, as measured by these search terms, is waning. If this approach to gauging investment and interest proves reasonable, it could become a powerful leading indicator for interest in the sector well in advance of anything in the industry can currently offer.

- Data center supply is likewise difficult to track, but not impossible. The brokerage community has a stranglehold on the most essential data in the industry, such as incoming supply, power ratings and bandwidth information and they don't part with it easily.<sup>33</sup> This thesis has endeavored to understand some of the drivers of data center supply decisions such as the proximity of fiber, power and Internet exchanges. Each of these factors play a large role in development decisions. The dearth of any of these factors would suggest that more supply will not be forthcoming for a given area.
- The importance of using US Census data in lieu of formal fiber optic cable infrastructure maps may end up being one of the findings than any of the other tools used or developed so far. This data is freely given by the US government and is remarkably comprehensive. The fact that fiber optic infrastructure data is not a public resource is a disappointment. Information about these routes is vital for mapping commerce and planning for further development and should be freely available.
- The refinements in the four-quadrant model for the data center industry serve to adapt this analytical tool for use in the data center market, where capacity is measured in power as well as in space. in modelling obsolescence patterns as the state of the art pushes data center PUEs to lower levels and power densities upwards. This refinement to the model can help investment firms to underwrite the risk of obsolescence in a given asset, assuming the variables in the other three quadrants can be gathered.

### Research Notes

Though much of this thesis works as a primer on the data center industry for real estate professionals and researchers, there is a fair amount of original research that comprises the bulk of the findings near the latter half of the paper, and those are what will be of particular interest to the reader. With this in mind, some background on methodologies is in order.

- The data center list used in the GIS analysis dates to early 2013. As such, it appears to be missing some facilities that otherwise would be prominent features of a more modern list, such as Quincy, WA. The definition of "data center" was determined by those that compiled the list.
- The list of Internet exchanges was an up-to-date data set as of December 2015, and therefore may possibly over represent Internet exchanges in comparison with more conventional data centers. All Internet exchanges

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<sup>33</sup> At least not to impoverished academics. If I were a potential tenant or investor looking into data center capacity in a local market with a potential commission to pay, circumstances would understandably be very different.

were compared against the data center list and there were no facilities in common between the two lists.

- The US Census broadband map used to determine fiber service was compiled in 2013, as were the railroad and transmission line maps.
- The SEC documents used for the demand section were taken up until 2014 and focused primarily on annual reports. While further research into which industrial sectors were most interested in data centers is possible, the effort was shelved in favor of looking into patent filings for similar data.
- The patent filing results were similar between looking only in the US and looking globally. In the interest of gathering a larger data set, the patent search was done globally and garnered similar results to an earlier search done solely on US patents.

Any of these results should be readily replicable and would greatly benefit from an expanded data set of data centers. Any data set that included data center power consumption or specifications would open the door for far greater research into the physical capabilities and growth of the Internet in the US.

## Conclusion

Each of the various chapters of this thesis have endeavored to tackle a separate issue in the field; Moore's Law is a boon to data center development, cloud computing will shift demand within the data center field but not reduce it, the four-quadrant model's update allows another tool for assessing market conditions, scraping information from SEC documents and patent filings offers leading indicators that show the direction of data center space demand, and that optimal data center development sites conform to a known geographic profile with proximity to fiber, power and Internet exchanges. Several further conclusions can be drawn from these chapters.

That data centers tend to cluster around Internet exchanges is a surprise to no one, but the tight proximity with which they do so suggests that infrastructural and commute considerations are the driving factors, not signal lag. In short, data center tenants appear very worried about people getting to their facilities quickly and that this factors into location decisions as much as proximity to power and fiber. This challenges assumptions about the depth of the data center submarket that chases cheap power and dark fiber at any cost. The 2013 data set used in this thesis suggests that the vast majority of data center tenants are located within 60 km of an Internet exchange, which themselves are predominantly located in central business districts. This finding casts data centers as being integral to the growth of cities and not as a specialty product type limited to only a select few markets across the US. Furthermore, the close proximity of data centers to Internet exchanges suggests that large data center markets can be found where there are many Internet exchanges.

This clustering phenomenon denotes a sensitivity to distance to which data centers were originally supposed to be immune; the fact that they prefer to be in or near cities and fall into agglomeration districts suggests that they will also conform to traditional monocentric city-style development patterns.

The discovery of trends in patent and SEC filing data surrounding data centers and cloud systems are valuable in that we now have a global and regional means of teasing out interest in data center presence and R&D. The fact that this interest appears to have been waning, in some cases since 2013, would suggest a cyclicity to data center interest that has not been as visible in the data center development business. The dearth of information about this product type in anything other than REIT prices or brokerage hearsay has prevented the data center market from becoming more efficient; now we have another tool with which to examine market activity. And currently that tool suggests a decline in corporate interest in the sector. This is sure to wax and wane with time, as all real estate markets always do.

The combination of agglomerations around Internet exchanges, themselves a product of urban environments, and early indication of market cyclicity in data center interest make this field suddenly seem more normal and less exotic than before. Too often the Internet is pitched as the *deus ex machina* of economic development, it seems to grow ad infinitum and generate new businesses that reshape our lives. One can be forgiven for assuming that the

data center market would follow suit, being defined by the Internet's constant growth and placelessness rather than being bound by real estate market laws of cyclicity and location. Even though data center owners are the landlords of the Internet, they still are bound to the terrestrial realm through the real estate balance of supply, demand and obsolescence.

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