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How Do Data Centers Make Energy-Efficiency Investment Decisions? Qualitative Evidence from Focus Groups and Interviews ¹

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Abstract

The data center industry is one of the fastest growing energy users in the US. While the industry has improved its energy efficiency over the past decade, engineering analyses suggest that ample opportunities remain to reduce energy use that would save firms money. This study explores whether and why data centers might limit investment in energy efficiency. Given the scarcity of empirical data in this context, we conducted focus groups and interviews with data center managers to elicit information about factors affecting their investments and used content analysis to qualitatively evaluate the results. Split incentives between departments within companies and between colocation data centers and their tenants, imperfect information about the performance of new technologies, and tradeoffs with data center reliability were the most pervasive factors discussed by participants. While we find some evidence that market failure explanations such as split incentives and imperfect information had a limited role in slowing adoption for participants, rival explanations such as the cost of acquiring context-specific information, and opportunity costs associated with alternate uses of funds or highly valued attributes played a larger role in slowing investment in energy efficiency.

Keywords

energy efficiency paradox; market failures; data centers; technology adoption

1. Introduction

As the world has become increasingly reliant on electronic forms of communication and services, demand for storing, managing, and distributing large amounts of data and information has grown. Data centers are the centralized repositories of computer servers that provide these services. Data center workload is projected to more than double between 2015 and 2020, while the number of servers installed is expected to grow by 25 percent (Cisco 2016; Shehabi, et al. 2016). This rapid growth has been accompanied by increasing energy consumption. In 2014, U.S. data centers consumed approximately 70 billion kilowatt hours, totaling about 1.8 percent of domestic electricity consumption, compared to roughly 30

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billion kilowatt hours in 2000 (NRDC 2014; Shehabi, et al. 2016).³ This electricity usage comes at a cost to the industry of about \$7 billion a year.

This study examines data center managers' investment decisions in energy-saving technologies and considers whether there is evidence of an "energy-efficiency gap." The energy-efficiency gap describes situations in which consumers or firms are observed to make limited or very slow investment in apparently cost-effective energy-conserving technologies (Jaffe and Stavins 1994) – that is, investments in technologies that are expected to pay for themselves because the upfront cost is outweighed by the net present value of future savings from reduced energy use. This study contributes to the literature by gathering qualitative data from data center managers that sheds light on whether and why such a gap might exist, including the potential contribution of market failures that would justify energy-efficiency standards or other policies.

Data centers are comprised of information technology (IT) equipment—servers, data storage, and networking devices—and the facility and infrastructure needed to house and maintain them, such as cooling and lighting. Adoption of energy-saving technologies and practices by data centers can weaken the link between volume of computing services and the energy needed to power them. The data center industry has already started to realize this potential. Electricity consumption has substantially slowed in the past decade even as demand for computing services has continued unabated (Shehabi, et al. 2016). Data centers have realized energy savings through both IT and infrastructure related measures such as improved air flow, temperature management and server virtualization (i.e., multiple applications run on a single physical server simultaneously instead of using a separate physical server for each application).

Despite recent improvements, potential opportunities for net cost savings from additional energy-efficiency investments exist throughout the industry (e.g., Mills, et al. 2008; Howard and Holmes 2012). Efficiency gains have been concentrated in hyperscale data centers, warehouse-sized facilities that provide computing services as their core business. While the hyperscale segment of the industry is growing rapidly, as of 2014 it represented about 20 percent of installed servers (Shehabi, et al. 2016). Extending best practices—such as increasing server utilization and aligning incentives between data centers and clients so that both realize cost savings from reduced energy consumption—to other parts of the industry could reduce electricity consumption below current levels by 25 to 45 percent by 2020, yielding billions of dollars a year in cost savings (Shehabi, et al. 2016; NRDC 2014; Brown, et al. 2007).

The paper is organized as follows. Section 2 summarizes competing hypotheses for why data centers might not adopt seemingly low- or negative-cost energy-efficient technologies and the implications of the different hypotheses for policy analysis. Section 3 summarizes how we collected qualitative data via focus groups and interviews and the characteristics of participating data centers. Section 4 presents the results regarding the roles of various factors in limiting or spurring adoption of energy-saving technologies and practices by participants.

³For a discussion of trends in data center energy efficiency in Europe, see Avgerinou, et al. (2017).

Section 5 examines to what extent factors identified as limiting adoption may stem from market failures—which could warrant a role for government action—versus rival explanations. The final section concludes.

2. Potential Reasons for Not Investing in Energy Efficiency

In assessing the costs and benefits of policy actions to reduce energy or emissions intensity, it is not uncommon for engineering-based analyses to assert that firms or consumers often fail to invest in energy efficiency even when it would be in their financial interest to do so. Such studies argue that the private sector does not take advantage of existing cost-effective opportunities, which net present value calculations suggest will pay for themselves over relatively short time periods (e.g., McKinsey & Company 2009). This has led to the prediction that consumers and firms will garner significant private cost savings due to government regulation mandating such investments.

The large cost-saving opportunities in the data center sector beg the question of why firms might not adopt them in the absence of regulation.⁴ There has long been debate in the scholarly literature about the energy-efficiency gap. Some have pointed to evidence of market failures - the failure of the private market to supply a good or service at the level consumers are willing to pay for - in context-specific settings (Gerarden, et al. 2017). Literature on commercial buildings has focused on imperfect information, split incentives, and capital market imperfections as possible market failures that could contribute to an energy-efficiency gap (Andrews and Krogmann 2009; Schleich and Gruber 2008).⁵ All of these explanations would potentially justify government intervention in markets, and so we investigate their relative importance in our study.

Imperfect information can slow the pace of adoption if firms wait to invest while others test out new technologies. In this situation, a small group of industry leaders often undertake most of the innovation, while other firms benefit from the information spillovers (Olson 1965). Split incentives can occur when the person that makes capital investment, use, or maintenance decisions does not pay for electricity. Individuals that do not bear the electricity costs may choose not to adopt energy-saving technologies and strategies or may undermine their effectiveness (Jaffe and Stavins 1994; Gillingham, et al. 2009). Finally, capital market imperfections (e.g., due to information asymmetries) could cause some firms to have difficulty securing outside financing for cost-effective investment opportunities, which could also contribute to limited or delayed adoption.

The literature also points to a rival hypothesis that factors unrelated to market failures explain the appearance of an energy-efficiency gap. Such factors generally fit within the paradigms of strategic decision-making (Cooremans 2012) and profit maximization more broadly.⁶ For example, if firms need company- or context-specific information to understand

⁴A 2013 California regulation mandates the use of specific energy efficient cooling, airflow, and fan technologies in data centers (California Building Standards Commission 2013). Energy consumption for the rest of the industry remains unregulated in the United States, despite a few federal initiatives to promote best practices.

⁵The presence of unpriced negative externalities, such as greenhouse gases and other air pollutants, also lead to market failures, but these are not expected to be factored into firms' private profit-maximization decisions so we do not consider them here.

⁶A profit-maximizing firm invests until the additional benefit from the investment just equals the additional cost.

the returns to energy-efficient technologies, then gathering this information represents a private cost to firms that must be accounted for rather than a market failure (Klemick, et al. 2015). Studies also have pointed to tradeoffs between energy-efficiency improvements and other valued attributes such as power, reliability, or quality that, while not always reflected in engineering analyses, make investing in energy-saving technologies less attractive (Huntington 2009; Gillingham, et al. 2009; Jaccard 2010; Klemick, et al. 2015; Klemick, et al 2017).^{7, 8} These types of tradeoffs are referred to in the economics literature as opportunity costs: they represent desirable features consumers or firms must give up when they choose a more energy-efficient alternative. Energy efficiency also competes with non-energy related investments, some of which closely align with a data center's core business; to be funded, an energy-efficiency investment needs to yield at least the same expected return. This reflects the opportunity cost of capital.

Consistent with this explanation is a form of strategic decision-making where a firm values attributes that more closely align with its core business (Cooremans 2011). The purpose of a data center is to provide a service. If the quality of that service is compromised by energy-efficiency improvements, this can result in a loss of customers and, ultimately, market share. Thus, energy efficiency is less likely to drive investment decisions when it involves tradeoffs with core business attributes.

In its guidance to U.S. federal agencies, the Office of Management and Budget (OMB) advises that the case for government intervention in markets is strongest when there is a demonstrable and sizable market failure (OMB 2003). In this context, identifying the extent to which market failures hinder investment in cost-effective energy-efficient technologies is both relevant and important. If the reasons why firms do not adopt certain technologies are unrelated to market failure, then regulation is unlikely to result in large cost savings for consumers or firms once the opportunity costs are considered.

3. Methodology and Summary Statistics

Researchers have used qualitative methods to better understand building energy management and design (e.g., Palm and Russell 2018, Gul and Menzies 2012, Pellegrini-Masini and Leishman 2011), as well as adoption of energy saving measures and technologies by iron and steel producers (Brunke, et al. 2014), pulp and paper plants (Thollander and Ottosson 2008), food retailers (Dixon-O'Mara and Ryan 2018, Klemick, et al. 2017; Ochieng, et al. 2014; Sullivan and Gouldson 2013), and heavy-duty trucking (Klemick, et al. 2015), among others. Howard and Holmes (2012) and NRDC (2014) interviewed data centers about the unique challenges related to addressing energy efficiency in the industry. Given limited data on data centers, we also used this approach, conducting interviews and focus groups to examine potential contributors to limited or slow investment in energy-saving strategies. We used a semi-structured approach to enhance consistency in the data and facilitate comparisons across participants.⁹ While prior literature in this area has mainly relied on

⁷The hypotheses we discuss are consistent with Sorrell, et al. (2011) and Thollander, et al. (2010).

⁸Conversely, it is possible that there are synergies between energy efficiency and other attributes, meaning that improvements in energy efficiency could actually lead to greater reliability or product quality in some cases. See section 4.5 for a discussion in the context of data centers.

interviews, we utilized both interviews and focus groups. In previous work, we found that energy managers enjoyed the opportunity to discuss these issues with their peers and that the dynamic and interactive setting of the focus group often enhanced and resulted in more in-depth discussion of the issues of interest than occurred in an interview setting (Klemick, et al. 2015; Klemick, et al. 2017). That said, interviews proved a useful way to engage data center managers working for industry leaders that were at times reticent to share their opinions freely in a group setting.

Frechtling and Sharp (1997) identified several advantages of the focus group and interview approach: It directly captures participants' perspectives, permits in-depth exploration to gain understanding of particular perspectives and experiences, and allows flexibility in how questions are asked to reflect unique circumstances and background. However, they also highlighted several disadvantages. The quality of the information depends on the facilitator's ability to moderate the discussion; insights are gleaned from participants' statements instead of directly observing behavior; and flexibility in how questions are asked can introduce inconsistencies across focus groups and interviews. Finally, recruitment of participants can be challenging and is unlikely to result in a representative sample.

3.1. Focus Group and Interview Protocol

To facilitate discussion, we used a semi-structured funnel design, discussing investment decisions generally before asking about the role of energy efficiency. Questions were open-ended to allow for possible unanticipated factors (Table 1). The facilitator also sometimes relied on prompts to elicit information on specific hypotheses from the literature when participants made no mention of them. Information from a questionnaire on energy-saving technologies and management practices was used to facilitate discussion of particularly appealing or unappealing features that influence adoption.¹⁰

We performed content analysis to evaluate transcripts from audio-recorded focus groups and interviews, relying on a directed approach to develop codes related to hypotheses on factors that may limit adoption of energy-efficient technologies (Yin 2003, Radcliff and Best 2005, Hsieh and Shannon 2005).¹¹¹² One hypothesis is that underlying market failures – e.g., imperfect information, split incentives, and capital market imperfections – limit or slow adoption of seemingly profitable energy-saving technologies. A rival hypothesis is that adoption of these technologies is slowed by other factors – e.g., the cost of gathering firm-specific information, tradeoffs between energy efficiency and other attributes, and a firm's opportunity cost of capital – that fit within the paradigms of strategic decision-making (Cooremans 2012) and profit-maximization more broadly.

⁹A semi-structured approach uses a moderator's guide, which lists the questions and topics to be discussed across interviews and focus groups. This approach allows the interviewer or moderator some discretion regarding the order in which the questions are asked and provides prompts to indicate when a topic is worthy of follow-up to facilitate a deeper understanding of a given topic as it relates to the hypotheses of interest.

¹⁰The questionnaire and moderator's guide are available in an online appendix.

¹¹Given the technical nature of the discussions and the fact that participants did not have access to questions ahead of time, we interpreted filler words – “um” or “err” or pauses – as indicative of a participant trying to gather his or her thoughts. These types of words were eliminated in the speech-to-text conversation process; we did not omit other informal speech mannerisms that might conceivably convey meaning.

¹²This form of coding is sometimes referred to as hypothesis coding and is a common approach to content analysis when attempting to assess researcher-generated hypotheses (Miles, et. al 2014).

Each segment of a transcript received a code related to a specific hypothesis; for instance, dialogue among focus group participants about how they collect information about the energy saving potential of new technologies was flagged with the code “imperfect information.” The coder then evaluated the context to categorize the discussion of the hypothesis as: (1) mentioned but not viewed as an important barrier or spur to adoption; (2) discussed but with mixed views of its role (i.e., sometime inhibiting and other times unimportant to or spurring investment); (3) widely viewed as slowing energy-efficient technology adoption; or (4) widely viewed as a factor that supports energy-efficient technology adoption.¹³ We also tracked information not related directly to specific hypotheses, such as factors important in making data center investment decisions; how energy savings ranked relative to other factors; sources of information managers used to learn about potential energy savings; who makes decisions about technology upgrades and how often; and whether and how payback calculations factored into decision-making.

We tested the coding algorithm by having multiple people independently code the same transcript by hand (i.e. we did not rely on automated coding algorithms), identified differences across coders or places where our initial coding algorithm did not adequately capture the discussion, and revised the approach to achieve consistency across transcripts. In section 4, we offer descriptive evidence related to these hypotheses, including how frequently a factor was discussed across focus groups and interviews and its role in adoption of energy-saving technologies. We included specific examples or quotes when representative of key themes identified via content analysis.

3.2. Participant Summary

We conducted six professionally facilitated focus groups with a total of 27 managers who made equipment purchase or maintenance decisions in one or more U.S. data centers.¹⁴ Each focus group was approximately two hours in length. The number of participants in a focus group ranged from three to six. In addition, we conducted seven phone interviews with industry leaders. Recruiting data center managers was difficult due to busy schedules and privacy concerns. We collaborated with national associations and industry experts to assist in recruitment.¹⁵

Focus groups occurred in three geographic areas. New York City/Northern New Jersey and Dallas/Fort Worth were in the top ten metropolitan areas in terms of concentration of U.S. data centers (JLL 2016). Boston represented a smaller but rapidly growing data center market. We conducted focus groups and interviews between October 2014 and June 2015. We excluded state and federal data centers due to different incentives to adopt energy-efficient practices compared to the private sector.¹⁶

¹³We also used sub-codes. For instance, a discussion that was coded as “tradeoffs with other attributes” and “widely viewed as a slowing adoption” would also be tagged with “reliability” if it discussed how a technology affects performance, redundancy, uptime, or reliability.

¹⁴Focus groups (FG) and interviews (INT) are labeled numerically throughout the document.

¹⁵Four focus groups were held at Data Center Dynamics conferences in Dallas and New York, and two focus groups were held at an AFCOM conference in Boston.

¹⁶Excluding this sector could potentially bias our sample. However, the proportion of US servers in federal government data centers fell from roughly 5–10 percent in 2007 to 1–2 percent in 2012–2014 (Shehabi, et al. 2016). Our sample does include private companies that provided computing services to federal government users.

Company affiliation was used to avoid duplication when recruiting but was otherwise masked to protect participant confidentiality. We attempted to recruit participants with a variety of attitudes and backgrounds on the potential importance of energy efficiency. While we actively recruited firms that did not participate in Energy STAR or belong to an organization that works to improve data center efficiency (e.g., Green Grid),¹⁷ the majority of our sample participated in these types of programs or organizations. As such, our sample is biased toward those more open to the implementation of energy-efficient technologies and practices. It also was challenging to reach companies that operated small data centers. This may be because managers of large data centers were more likely to attend association conferences, the main method used to recruit participants.

In our sample, 41 percent of participants worked at companies with more than 50,000 servers, while about a quarter had less than 2,000 servers (Table 2). About one-third of participants hosted cloud or hyperscale data centers, another third hosted colocation data centers (leased multi-tenant spaces where companies run computing equipment without having to manage their own data center), and 18 percent hosted high-performance or scientific computing for data-intensive processes.¹⁸ Data centers whose main line of business was IT services were most common (44%). Participants also supported banking or financial services (38%), health care (26%), media and communications (18%), and industries ranging from energy to state and federal government to manufacturing (26%). About 70 percent were located in more than one state; a few had an international presence (15%).

Half of the participants had direct oversight over five or fewer data centers, while 41 percent managed six to 20 data centers. More than half of the participants also managed at least one mega- or utility-scale data center (larger than 10,000 square feet). This category includes most colocation facilities. About 25 percent managed an enterprise or corporate data center (greater than 5,000 square feet), which fills an IT support function rather than being the company's main line of business. About 20 percent of participants managed localized data centers (less than 1,000 square feet) or server rooms or closets (less than 500 square feet) for an individual office or call center. One third of participants reported a major infrastructure upgrade once every two years. More than half of participants also replaced servers on a three- to five-year cycle. Over 70 percent of participants took part in either an energy-efficiency voluntary program, while almost 40 percent had a third-party energy audit in the last three years.

3.3. Adoption of Energy Saving Technologies by Participants

We also asked participants to complete a questionnaire listing 19 specific energy-efficiency enhancing facility and IT technologies and strategies. In addition, managers of colocation data centers were asked about three pricing strategies to incentivize energy efficiency. Figure 1 summarizes the questionnaire responses by data center size. Along the x-axis, facility

¹⁷EPA and DOE's Energy STAR buildings program recognizes top performers in energy efficiency through certification of individual facilities as well as portfolios of buildings or plants.

¹⁸The degree to which a data center operated as a colocation facility varied from less than 10 percent to over 90 percent of racks. More than half of the sample also leased space from others, though 25 percent leased a relatively small portion (i.e., 20 percent or less). In addition, most data centers occasionally outsourced facility management.

management strategies are on the left-hand side, IT management strategies are in the middle, and pricing strategies are on the right-hand side.

Facility Management Strategies.—Air flow management strategies (e.g., hot/cold aisle configurations, blanking panels, variable speed fans, energy-efficient air handling units) are generally used at higher rates than some heating, ventilation, and air conditioning (HVAC) system adjustments (e.g., air and water-side economizers, temperature set points). While we do not have precise estimates of payback for each technology, the information available suggests that data centers tended to adopt technologies with quicker expected paybacks (e.g., less than two years) at a higher rate.¹⁹ There are exceptions. Despite minimal upfront costs and a relatively quick payback, localized data centers incorporated temperature set points at lower rates. Likewise, adoption rates for strip curtains (i.e., overlapping strips of plastic that partition a space) were lower than for many other technologies across all three data center sizes. Consistent with recent industry trends showing higher energy efficiency among larger data centers (Shehabi, et al. 2016), adoption of many technologies and practices was noticeably higher among utility-scale data centers, followed by enterprise and then localized data centers.

IT Management Strategies.—Over 80 percent of respondents had adopted energy-efficient server hardware, virtual servers, and decommissioned unused servers, and 74 percent had consolidated lightly used servers, all of which are expected to payback relatively quickly due to low upfront costs. Though others have found virtualization to be less common in smaller data centers (Bennet and Delforge 2012), all the localized data centers in our sample used server virtualization. Over half of respondents also adopted measures to improve management of data storage and/or IT power management software, although adoption rates were somewhat lower among localized data centers. Under- or over-clocking—dynamically adjusting the clock speed of a computer’s processor or memory to match IT workloads—was less widely adopted.

Pricing Structures.—Among respondents who managed utility-scale facilities (which typically provide colocation services), 37 percent charged for both space and actual power consumed (either within set block amounts or according to actual electricity used), 32 percent based pricing on space alone, and 16 percent said that they would not use space-only pricing again or consider it in the future. In contrast, among the localized data center managers who responded, only space-based pricing had been utilized to-date, though they signaled an openness to using other pricing strategies in the future.

¹⁹Barriers that prevent mixing of incoming cold air and hot exhaust air (cold- or hot-aisle containment), tiles that guide cool air to servers (directional floor tiles, blanking panels), air conditioning unit devices that allow air flow to vary as cooling demand fluctuates (variable fan or speed drives), and higher temperature set points are frequently described as paying back in less than two years. Company statements and research indicate that investments in cooling method often have higher upfront costs, particularly retrofits, but can still yield large energy savings in some circumstances. See Van Geet (2017), Pacific West Air Conditioning (2014), Green Grid (2011), Wathaifi (2009), and https://www.energystar.gov/products/low_carbon_it_campaign/12_ways_save_energy_data_center/.

4. Results

Section 4.1 discusses the extent to which data center managers who participated in our focus groups or interviews used financial budgeting tools, and whether they reported investing in technologies that pay back relatively quickly. If a firm's desired payback period is substantially shorter than the equipment lifetime, indicating that the net present value of energy savings far outweigh upfront cost, this is suggestive of an energy-efficiency gap. Sections 4.2 – 4.5 offer descriptive evidence related to hypotheses for why this observed gap might occur based on the coding of the focus group and interview transcripts. We highlight the roles of uncertainty and imperfect information, split incentives, financial constraints, and tradeoffs with other data center attributes in energy-efficiency investment decisions.

We find that participants often relied on financial budgeting tools, though the level of detail and sophistication varied. Most data centers expected a payback of between one and five years, with some flexibility when considering non-financial factors. We find that the most commonly discussed factors limiting adoption of energy-efficient technologies were within-company split incentives and tradeoffs with other attributes, though both played a mixed role. The roles of split incentives in colocation facilities and uncertainty and/or imperfect information in slowing adoption also were discussed in every focus group and most interviews. The opportunity cost of capital was only discussed in a subset of focus groups and interviews but seemed important in those instances. Neither split incentives between firms and contractors nor access to outside financing were dominant concerns for participants. We summarize the relative importance of these factors and the extent to which the evidence supports market failure versus rival explanations for limited adoption in Section 5.

4.1. Payback Calculations

Participants in every focus group and interview stated that their companies utilized a financial budgeting tool to aid in decision-making. Several participants noted that the level of detail in their analyses varied by type of investment. For instance, payback analyses were not needed for well proven “*no-brainer*” technologies (INT#2) or IT investments given the rapid replacement cycle of the equipment (INT#1).

Some firms emphasized the need to perform a more comprehensive financial analysis than a simple payback calculation to gain support within the company for a project (FG#6). Interviewees indicated that they incorporated factors such as asset depreciation, water usage, labor costs, maintenance and repair costs, facility age, installation time, uptime impacts, and the opportunity cost of lost space for larger equipment (INT#3, INT#4, INT#6, INT#7). Other participants mentioned accounting for service contract expenses, government or utility incentives, retraining, and installation costs (FG#1, FG#2, FG#3, FG#4, FG#6), although not all factors were included quantitatively (INT#1, INT#2). One interviewee noted, “*An investment decision needs to make good sense...I purposely did not say economic sense because sometimes you make good sense for benefits to brand or acquiring a new customer...*” which are difficult to incorporate into a financial budgeting tool (INT#2). Two interviewees highlighted the importance of discounting cash flows when making these types of calculations (INT#2, INT#4).

Electricity usage and rates featured prominently in these calculations for most companies. One participant noted, “*ten to fifteen years ago [energy consumption] flew way under the radar, and it just didn’t cost that much to run and build a data center, [but] every year... our utility rates are going up. It’s become a huge expense, and it’s got the attention of all of our businesses*” (FG#1). However, another participant suggested that energy consumption played a less important role for companies whose main line of business was something other than IT (FG#3).²⁰

A few participants in every focus group and all but three interviews required paybacks between one and five years. However, many suggested that these paybacks are not hard-and-fast rules. One participant noted, “*there needs to be a really good reason to consider a retrofit with a really long payback*” (INT#6); another explained, for “*an upgrade of an existing facility, [the payback] would have to be fairly short to compensate for the risk of making changes*” (INT#3). Several participants said that regardless of the payback they may consider an investment for a good marketing reason (e.g., making the company look “*green*”) (FG#2, FG#4). Section 4.4 discusses the role of customer concerns in adoption decisions.

4.2. Imperfect Information

Participants in every focus group and four interviews discussed imperfect information and uncertainty as having a moderate impact on adoption of energy-saving technologies. While many participants avoided the “*leading edge*” (INT#1) and preferred to wait for others to test out new technologies, most reported making investments to improve the efficiency of data center facility infrastructure and were confident that these investments would yield a positive return on investment (ROI) based on their own testing or information from other firms. Because the information most valuable to firms was typically company- or facility-specific, it is difficult to argue that this type of imperfect information represents a market failure. That said, we cannot completely rule out a small role for information-related market failures in data center investment decisions since there are some information spillovers among firms.

Information about Current Energy Use.—Data centers typically tracked and communicated information about energy efficiency in terms of power usage effectiveness (PUE), the amount of power used by the data center as a whole divided by the amount of power used by IT equipment (Belady, et al. 2008).²¹ Use of the PUE metric was widespread among participants but varied with data center size. More than 80 percent of mega-scale and enterprise facilities tracked this information, but only 29 percent of localized data centers measured PUE. PUE among firms that tracked and reported this information also decreased with facility size (indicating an improvement in efficiency).

The results of the content analysis indicate that participants in 46 percent of focus groups and interviews felt that information about the *current* energy use of a data center did not

²⁰This finding is consistent with Cooremans (2012) regarding the importance of investment characteristics in decision-making.

²¹A PUE of one indicates that a data center uses no additional power for lighting, cooling, power distribution or facility operation beyond what is drawn by the IT equipment; a PUE of two indicates that for every unit of power consumed by IT equipment, another unit is used for facility operation. Participants reported a median PUE of 1.7 for localized facilities, 1.55 for enterprise facilities, and 1.4 for mega/utility-scale data centers.

limit investment in energy efficiency, while 31 percent expressed mixed views, and the remainder either viewed it as limiting investment or did not discuss it. Several participants noted that real-time monitoring of PUE and energy consumption at the individual facility—or even the rack (which vertically houses multiple servers) or server level—is an important prerequisite to improved efficiency (FG#1, FG#4, FG#6, INT#4). One interviewee explained, “*The site techs are constantly looking at [real time PUE] to try and figure out how they can be more efficient, and they’re very competitive*” (INT#4). The same interviewee called monitoring and control systems the “*best tool you can put in the data center*” to motivate energy-efficiency investments (INT#4). However, some participants complained that PUE is not always comparable across data centers because of a lack of standardization in the way it is measured and calculated (FG#2, FG#3, FG#4).

Not all participants had advanced monitoring capabilities. One participant said his data center did not meter energy use at all (FG#5); another called for more research to understand the relationship between specific technologies and overall energy use (FG#6). Granular energy monitoring systems were regarded as particularly useful in colocation data centers where real-time feedback on PUE allowed them to charge tenants for actual electricity consumption, an approach that can strengthen the incentive to conserve energy (INT#2, FG#4).

Information about New Technologies.—Content analysis reveals that participants in the majority of focus groups and interviews (62 percent) expressed mixed views about whether imperfect information about *new* technologies limited investment in energy efficiency, in part because they viewed the quality of the information as different across sources. This evidence, in combination with participants’ views on the role of information about current energy use, we interpret as providing moderate support for the hypothesis that imperfect information limits energy-efficiency investments.

Participants evaluated new technologies using a variety of information sources, including manufacturers, in-house testing, conferences, and peers (Table 3). External consultants and trade publications were less common, particularly among focus group participants. One participant commented, “*I have a bookcase of magazines I don’t have time to read*” (FG#1). Information provided by government was not mentioned as a primary source by any participant, except for one interviewee who consulted Energy Star.

Participants in every focus group and interview mentioned using information from manufacturers and vendors as a starting point for research about new technologies. A participant explained, “*An important stream of information about what is new and upcoming in the industry technology comes from our vendor partners and OEMs [original equipment manufacturers]... Those folks are always bringing to us what’s new, and what’s cutting edge*” (FG#1). However, other participants stressed the limitations of energy-efficiency data provided by manufacturers: “*The technology is growing and changing so fast that [manufacturers and vendors] don’t have the proper metrics, or at least they’re not staying far enough ahead of the technology to get hard data back to the customers they’re trying to help*” (FG#4). Because data centers are individualized facilities that vary in size, climate, load and other dimensions, average estimates are of limited usefulness (INT#2, FG#5,

FG#6). One participant summed up these limitations: *“Have you bought a car that has a sticker that says that they usually get 25 miles to the gallon, but when you take it out on the road, you drive it, and you only get 18 to 20? The sticker value isn’t how it actually runs”* (FG#3). Participants also cautioned that while information about facility energy efficiency is usually reliable, data about the performance and energy use of IT equipment is *“kind of worthless”* (FG#4).

Because of the need for facility-specific data about new technology performance, many firms conducted their own testing before widespread adoption. For instance, one participant thought directional floor tiles were *“a gimmick at first, but we actually tested them and they worked exactly as designed... We saw rack temperatures go down by two degrees”* (FG#6). Some large firms even had in-house R&D divisions to develop and pilot new technologies (INT#2, INT#3, INT#4, INT#5, INT#6). However, others—particularly, small- and medium-sized firms—stated that lack of resources and expertise, and concerns about uptime, limited their ability to conduct testing (FG#4). Manufacturers also sometimes facilitated free in-house pilot testing to demonstrate effectiveness (INT#1, FG#2).

Learning from industry peers was repeatedly highlighted as an important source of information. One interviewee discussed the value of initiatives like the Open Compute Project, *“where the participants ... make all the details available and talk very frankly about the positive and negative experiences”* (INT#7). Participants reported that their willingness to adopt a new technology is much higher once other companies report a positive ROI (FG#2, INT#1, INT#7). One participant was motivated to reconsider adopting blanking panels and cold aisle containment, *“now that I know that [a fellow participant] saves 16 percent”* on energy costs (FG#5). A few technologies are already widely proven. As one interviewee noted, *“Nobody needs to write another white paper on the benefits of airflow and the payback. It has been proven to be an extremely economically rational decision”* (INT#2).

The most valuable information spillovers do not always come from the largest data centers. One interviewee noted that, *“Often the stuff that’s more innovative is not coming from the big guys. It’s coming from some of the smaller shops that are really doing things differently”* (INT#4). Some also pay attention to energy-efficiency practices in Europe (FG#5) and in industries such as manufacturing (FG#4, INT#4). The reliance on peers and hesitation to be a first mover can slow adoption for the most nascent technologies. One interviewee passed on geothermal cooling because, *“it’s got to have spent some time in the field. We would not purchase the latest and greatest... I don’t know that many people [who] have it”* (INT#1). Another participant stated, *“In the IT world and the data center world, everyone is still trying to come up with what is the best solution, so everything is a novelty, everything is expensive”* (FG#4).

Uncertainty about New Technology Performance.—Even data centers that took advantage of in-house testing or knowledge spillovers from peers still faced uncertainty about future energy savings. For instance, energy savings may depend on how intensively a facility will be used (INT#7). If manufacturer energy-efficiency estimates are contingent upon utilization, it can be difficult to develop solid payback estimates (FG#6). A manager

explained, “*the most difficult things to model are customer behavior and how much they’re going to use a piece of infrastructure; if they don’t use it much, the efficiency is bad,*” and, “*just like a bus driving around with only one passenger in it... it’s just far less efficient than if you had a hundred people on there*” (INT#2). Some companies addressed this uncertainty by building more capacity—and hence using more energy—than they needed initially to allow for growth over time, while acknowledging that energy-efficiency performance was poor while the facility was under-utilized.

Decision-makers’ attitudes towards risk and uncertainty also can influence technology adoption. While participants acknowledged that financial gains from new energy-saving technologies can be substantial, the threat of lost uptime looms large. Participants described this risk by saying, “*If I screw up, I could take the company down,*” (FG#2), and “*the risk [of shut down] may kill [the proposed upgrade] dead in the water. These are the most risk averse human beings you’ll ever meet, in the data center industry*” (FG#3). In contrast, an interviewee noted, “*We are a little bit more tolerant to risk. We are a little bit more experimental*” (INT#3).

4.3. Split Incentives

In this section, we discuss the potential for split incentives between departments within a data center; between data center owners and lessors; and between data centers and the contractors repairing or maintaining equipment. Content analysis revealed moderate evidence of split incentives between departments within a company, and between lessors and lessees, but only weak evidence of split incentives between outside contractors and data centers. In many cases, companies employed strategies to reduce cross-department split incentives such as integrated oversight teams, employee training, and individual department charges for electricity use. Realignment incentives between lessors and lessees appeared more difficult unless the data center charged the lessee for actual electricity use.

Company.—A data center’s IT department is responsible for ensuring the service, safety, and security of data—the core business of a utility-scale data center—and makes purchase and upgrade decisions for servers and software with those goals in mind. The facilities department—which can be viewed as providing support services to the business—is responsible for maintaining buildings and infrastructure, and placing equipment to ensure air flow and heating and cooling needs are met. It also typically pays for the electricity for the entire data center (NRDC 2014). Without coordination between them, it is possible that the IT department will make purchasing decisions that undercut energy-efficiency improvements to air flow or other aspects of heating and cooling on the facilities side.

The potential for split incentives within a data center due to disconnects across departments was discussed in every focus group and interview. Content analysis revealed that participants in 62 percent of focus groups and interviews viewed within-company split incentives as playing a mixed role in energy-efficiency investment decisions, sometimes hindering and other times spurring these investments; for the remainder, they did not affect decision-making. We interpret this evidence as moderate support for the hypothesis that this factor limits technology investment.

Siloed decision-making was common: *“IT and facilities are separate parts [of the company] that don’t meet until you get very, very high up”* (FG#2). Several participants noted that the IT department is often more concerned with maintaining service than with saving energy: *“my IT department, frankly, [is] not very concerned about the efficiencies and the technologies of the data center. They want a service, and they want it when they want it”* (FG#1). A disconnect between departments was also described as affecting investment decisions for new data centers; one participant stated that project designers have a disincentive to invest in energy-efficient equipment with a higher upfront cost, even if it saves money over time, because they receive a bonus to come under budget (INT#1).²²

That said, participants in three focus groups and every interview implemented strategies to better coordinate across departments. For instance, in some companies a team or person was assigned an explicit oversight role to help insure more integrated decision-making. One interviewee observed, *“It’s managed in a very integrated way. Obviously, it’s a big team so there are subgroups...Each of those [subgroups] has a budget, but that’s all managed and coordinated by one central [team] within the whole organization”* (INT#6). Training was also utilized in some companies to encourage IT staff to consider energy efficiency in server purchase decisions.

A few participants addressed within-company split incentives by charging electricity use back to individual departments. One manager noted that *“the electricity costs come out of the data center budget, and [then] we provide a consumption-based charge back to our product groups or product units internally”* (INT#3). Another participant observed that, while it is not easy to charge the electricity back to the users, it is important to *“make our user realize what the real cost of their equipment is”* (FG#1).

Colocation Facilities.—A colocation facility leases space in a data center to another party. The data center itself typically provides and manages the cooling, heating, and other support infrastructure—including paying for electricity—while the tenant often determines the IT equipment utilized (Bullock 2009). The potential for split incentives occurs when the cost of electricity is not passed through to the lessee, resulting in equipment choices that may undercut the overall energy efficiency of the facility. There are many challenges to aligning incentives between service provider and tenant in colocation facilities, including the desire to keep charges low, competing priorities (e.g. reliability, security), inadequate monitoring to reflect the actual cost of power and cooling in pricing, and utility incentive programs aimed at the service provider instead of the tenant (Howard and Holmes 2012, NRDC 2014).

Misaligned incentives between lessees and lessors were discussed in every focus group and five interviews. Participants in most focus groups and interviews (69 percent) expressed mixed views regarding the role of split incentives in colocation facilities on energy-efficiency investment decisions. This may reflect heterogeneity in participants’ influence over tenant equipment choices (short of directly pricing electricity use). One interviewee

²²Howard and Holmes (2012) also found evidence of split incentives between the facilities and IT departments for the data centers they interviewed. They found that having one person responsible for both facilities and IT equipment decisions was more common among companies whose core business was data center services.

noted, *“I don’t get involved in anything inside the racks”* (INT#7). Others offered guidelines and investment advice to tenants based on observed energy use (FG#2, FG#3). Participants found that some tenants were attracted to more energy conscious data centers (FG#1, FG#2), while for others, *“the primary expectation ... that the data center provide reliability (100 percent uptime). They don’t want to bear the risk of energy costs and don’t want to have to think about energy efficiency”* (FG#4).

According to several participants, a typical contract in the colocation industry was based on square footage or the number of racks utilized, adjusted to account for expected energy use. Some contracts also accounted for PUE (INT#6, INT#7). However, several participants observed that it is becoming more common to charge for actual power usage. One interviewee stated, *“the idea is to align incentives between us and the customer so that both parties win when the customer is more efficient”* (INT#2). We asked participants that routinely lease space in colocation facilities who pays for their electricity. Several participants stated that they are charged for the electricity they use. Others noted that the owner paid for the electricity and did not directly pass these costs along to the tenant.

Several focus groups identified two reasons why charging for actual usage is growing in popularity (FG#1, FG#2, FG#3). First, square footage is a poor proxy for energy use for some types of users (e.g., scientific computing uses a given physical space more intensively). When a data center fails to account for these differences, it charges the same amount to a tenant that uses 5 kilowatts per rack as one that uses 50 kilowatts per rack. Second, wider use of monitoring technology has allowed data centers to track how energy use varies at the rack or server level. One interviewee noted that, once you have this type of monitoring data, pricing energy to affect tenant investment choices is possible: *“As a colocation provider, we will always be siloed from the IT decisions of the customer. So in some ways there’s no way to overcome that barrier. The way we try to do that is with information and incentives, providing real-time data and aligning billing incentives to enable us and customers to make optimal decisions”* (INT#2).

Firm-Contractor Relationships.—About one third of participants outsourced all maintenance and repair, while about 40 percent sometimes outsourced this service. However, we find weak evidence that split incentives between contractors who maintain and repair the equipment and data center managers limited energy-efficiency investments. This factor was only discussed in three focus groups and only highlighted as a major issue in one: *“Field technicians aren’t necessarily up to speed with their own products. That’s a big problem for us as the end users in a mission critical environment”* (FG#6). In this instance, the data center relied on in-house staff to correct or circumvent problems. Participants in the other two focus groups noted that, either outsourcing of maintenance and repairs had no bearing on data center energy efficiency (FG#4), or close monitoring of equipment meant they could raise it with contractors immediately if something was not working properly (FG#5).

4.4. Financial constraints

In reviewing participants’ statements on whether firms faced financial constraints, we distinguish between limited access to outside financing and competition from within the firm

for other uses of existing funds (i.e., opportunity cost of capital). We do not find much evidence to suggest that limited access to outside financing hindered investments, though rebate programs often helped incentivize investments with longer expected payback periods. Competition among projects within the firm for available funds appears to substantially slow energy-efficiency investments.

Access to Outside Financing.—While participants varied in their use of internal vs. external financing for major investments, no participant mentioned the inability to obtain a loan as a limiting factor in energy-efficiency investments.²³ Participants in 62 percent of focus groups and interviews indicated that outside financing played no role in their investment decisions. Only a single interviewee described lack of access to financing as limiting investments, with the remainder expressing mixed views or not discussing outside financing. Thus, we find weak evidence that access to outside financing limited investments in energy efficiency. As one participant explained, *“Financing for me has no input whatsoever. It is not a money availability issue...”* (FG#2). Participants in another focus group noted that financing decisions have no bearing on the choice of technology; only after they have selected the best technical solution do they identify financing. Another participant stated, *“...[t]here is a lot of financing available from manufacturers these days”* (FG#3).

Participants in most focus groups and interviews thought rebates from utilities or government programs made energy-saving investments more attractive.²⁴ Many characterized them as a major factor in tipping the scale toward adoption: *“I have spent many millions on things that I wouldn’t have spent if the tax incentive hadn’t been in place”* (FG#2). One participant explained that government incentives were *“the only thing that ... took it [the LED lighting retrofit] from being completely unrealistic from a price and return on investment [perspective] to something we couldn’t turn down”* (FG#2). Another participant said that he had not invested in energy-efficient lighting in part due to the lack of local utility incentives (FG#4). For some, tax incentives also played a key role in decisions about where to locate a new data center (INT#3, INT#6), though one participant noted that siting incentives are not necessarily related to energy efficiency (FG#2). Several emphasized that working closely with the utility is essential; some even negotiated electricity rates directly when making upgrade decisions.

Opportunity Cost of Capital.—Participants in 54 percent of the focus groups and interviews raised competing uses of capital or the discount rate as a limiting factor in their investment in energy-saving technologies, leading us to categorize this factor as having a moderate effect on technology adoption. One manager explained, *“I have to show short-term payback because I’m competing with other people within the company. You know, somebody wants to build a building or buy a piece of medical equipment or do something, I’m competing with them”* (FG#4). Another stated, *“If I am doing an efficiency improvement and I can’t make it pay for itself in three years, there is virtually no chance I*

²³While we do not know exactly how many participants rely on internal vs. external financing, discussion suggested they use a mix. Cooremans (2012) and Klemick, et al. (2017) found that internal financing is prevalent in other sectors; as here, energy efficiency often competes with non-energy investments for internal capital.

²⁴For an overview of incentive and rebate programs offered by utilities, see Howard and Homes (2012).

am going to get the money... because we can take that same money, invest it in something else that is going to grow the business, and return profit”(FG#2). Others indicated that all capital investments come out of one budget, so energy efficiency needs to make the same return as other capital investments (FG#5, FG#6). One interviewee noted, *“we have a responsibility to our shareholders to get the most return for the amount of money that we have”*(INT#3).²⁵

Participants’ statements highlighted the importance of the discount rate used to evaluate the net present value of an investment: *“[The preference for short payback periods] speaks to alignment of incentives and also includes ideas about time value of money and needing to discount future cash flows...”*(INT#2). If a firm uses an internal rate of return that is higher than the discount rate commonly used to compare the upfront cost to the discounted savings expected from an energy-efficient technology (i.e., a net present value calculation), then lack of adoption may indicate a decision to pursue more attractive opportunities available to the firm, not the presence of a market failure. Analyses of new technologies that use a private discount rate also better reflect the likely private benefits to firms.

4.5. Tradeoffs between Energy Efficiency and Other Factors

This section summarizes participant statements about the potential for tradeoffs between improved energy efficiency and other attributes when adopting a new technology. These factors may make a new technology genuinely less (or more) attractive or costly, but are not typically reflected in NPV calculations. In general, a key concern of participants was how energy-efficiency investments affect data center reliability. Heterogeneity in climate and other geographic or data center-specific concerns also factored into adoption decisions for some types of energy-efficient technologies. While not discussed in every focus group and interview, many participants considered how easy a new technology would be to maintain and how it would be viewed by customers. Overall, we find strong evidence that these factors slow adoption of energy efficiency, with participants in 85 percent of focus groups and interviews highlighting at least one tradeoff as limiting their investments.

Reliability Tradeoffs.—The industry uses the terms reliability and uptime to refer to the amount of time a data center is operational. As a participant stated, *“We are shooting for 100 percent uptime”*(INT#4; INT#1). To ensure reliability under a variety of conditions (e.g., unanticipated power outages), data centers often build redundancy or backup into their systems (Brown, et al. 2007). Particularly for utility-scale data centers, a loss in reliability could compromise the core business and affect revenues, since it is a metric of utmost importance to many customers. It should therefore come as no surprise that potential tradeoffs between energy efficiency and reliability were discussed in every focus group and all but one interview. Focus groups and interviewees were evenly split between the view that tradeoffs with reliability slowed the adoption of energy-efficient technologies, and that it played a mixed role that did not always hinder adoption.

²⁵Mills, et al. (2008) also pointed out that energy efficiency improvements in high-tech industries such as data centers often compete internally with other capital investments that pay off very quickly.

As one participant described, *“everybody wants you to save money, but doing certain things where you might shave some kilowatts is not worth the risk of any impact [it] would have on reliability”* (INT#1). Another participant observed, *“if [an energy-efficient option] in any way compromises uptime, it is a non-starter”* (FG#2).²⁶ Examples of energy-efficient technologies that participants said they did not use due to their impact on reliability included power management systems for servers and flywheels as backup power. Some participants also mentioned that concerns about how higher ambient temperatures may affect system reliability have slowed adoption of higher temperature set points.

Other participants recognized that data centers set higher redundancy requirements than they need, so there may be opportunities to lower energy costs without compromising reliability, particularly for less critical operations (e.g., opening a Word document vs. tracking missiles). A participant noted, *“we will spend the money to draw more power because we want to protect ourselves from failure. We’ve done that and we’ll continue to do that for those applications that we deem critical. But [for] those that aren’t, we won’t spend that kind of money”* (FG#4). Another participant agreed, noting that it is important for the industry to rethink its approach to redundancy for non-critical uses (FG#5).

A few participants also noted that the tradeoff between reliability and energy efficiency may become less important in the future and could even be synergistic in some cases. One participant noted that greater reliability allows for more stable temperatures, which then allows for increased rack density and more effective cooling (FG#4). Another noted that increased virtualization improves energy efficiency while making it easier to manage data center operations (FG#6).

Data Center Heterogeneity.—Climate was acknowledged in all focus groups and interviews as a factor that can affect how well certain energy-efficient technologies function in a data center. For instance, differences in ambient temperature and humidity can affect how airside or waterside economizers function. Likewise, hotter climate makes it more difficult to run servers in power-saving mode and shortens equipment longevity. Local safety and fire codes were also mentioned in several focus groups as a potential barrier to investment.

When siting a new data center, temperate climates were viewed as more attractive from an energy standpoint but unlikely to outweigh factors such as distance to clients, customer demand, zoning, and real estate prices. Several participants noted that the largest data centers in the country are in very hot climates. One manager we interviewed observed, *“cooler climates lead to greater efficiency of the data centers, so that’s a consideration always. But in the scheme of things, the heat generated within the data center far outstrips the heat that might come in through the [building] envelope”* (INT#2). That said, another participant stated that, in the past, siting a facility in a good climate for energy efficiency *“was an afterthought. Now, it’s more part of the discussion”* (FG#4).

²⁶These statements are consistent with Mills, et al. (2008): risks of power failure are often overestimated, resulting in “overdesign” of backup systems and “strict emphasis on proven reliable technologies.” Howard and Holmes (2012) noted that a major challenge to improving data center energy efficiency is an “extreme focus on reliability.”

Participants in five focus groups and four interviews discussed space constraints and the ease with which energy-efficient technologies could be integrated into an existing system as factors when evaluating potential upgrades. If a new technology cannot be supported by the current platform or requires substantial system adjustments, then it is less likely to be adopted. Two managers also noted that since their firms were already more energy efficient than average, many of the technologies available were not expected to deliver additional savings for them.

Maintenance Tradeoffs.—The relationship between energy efficiency and maintenance of new equipment was discussed in four focus groups and all but one interview. As one participant described, *“there’s equipment that might be really efficient but is designed in a way where replacing anything is a royal pain. We work really hard to make sure that all those kinds of jobs can be done easily and efficiently”* (INT#6). Several participants also voiced concerns about the degree of familiarity the engineering staff has with new more energy-efficient equipment. One participant stated, *“I’d rather have an OE [operations engineer] who’s more comfortable with the equipment that he has, that is less efficient, than have a brand new piece of equipment come in and have to re-learn it”* (FG#6). A related issue voiced by a few focus group participants was concern that fewer companies provide maintenance services or parts for newer technologies than for existing but less efficient technologies.

Customer Concerns.—Customer concerns about energy-efficiency investments were discussed in five focus groups and three interviews. One participant noted that investments that helped the company *“tell a good story”* to customers nudged them toward greener technologies, even though the primary motivation for investment was cost savings (FG#1). Other participants observed that an associated marketing or public relations opportunity gave them greater flexibility about the expected ROI (FG#2). While many participants expressed the desire to invest in energy efficiency where it made the most economic sense, the possibility of greenwashing was raised (i.e., doing something that looks good but doesn’t reduce energy use). That said, a few managers stated that customer perception was rarely a factor in energy-efficiency investment decisions (FG#4, INT#5). Participants also gave examples when customer perceptions precluded certain technology options. For instance, several participants would not use strip curtains *“[because of] the aesthetic factor. Regardless of how much energy savings there [are] you cannot bring people into the data center and see meat locker curtains”* (FG#6). Other participants mentioned that they stopped short of industry recommendations for adjusting temperature set points due to customer concerns (FG#4).

5. Discussion

Table 4 summarizes the results presented above based on how often a specific explanation for the energy-efficiency gap was discussed, the degree to which respondents felt it limited energy-efficiency investments, evidence that slowed adoption may have resulted from a market failure, and potential improvements that could be made to policy analysis, which mainly rely on engineering-based NPV calculations, to address analytic gaps. While these measures are inherently subjective—based on our interpretation of participant statements—

in general, we find that some aspect of each explanation was of concern to participants. Uncertainty and imperfect information about the firm-specific efficacy of technologies, split incentives within a company or between a colocation data center and its lessees, and tradeoffs between energy efficiency and other attributes of specific energy-saving technologies received the most widespread discussion among participants. The opportunity cost of capital was also discussed in over half of the focus groups and interviews.

In general, we find that the hypothesis that market failures contribute to an observed energy-efficiency gap in the data center industry is only partially supported. We find little evidence that financial constraints limited adoption of energy-efficiency investments. While split incentives within the company and for colocation facilities were discussed at length, participants often developed mitigating strategies to limit their effects on investment decisions. Participant statements supported the notion of information spillovers between firms; however, the information most valuable for investment decisions was often context-specific, which means information is more of a private than public good.

A rival hypothesis for which we find broad support is that tradeoffs with other attributes play an important role in slowing energy-efficiency investments. Key among these were tradeoffs with the quality of the services data centers provide (e.g., reliability). Location- and space-specific factors also played an important role, reflecting heterogeneity among data centers in their opportunities for saving energy. Participant statements also provided evidence that competing uses of capital within the firm limited investment in energy-saving technologies. The presence of such factors is not generally viewed as a sufficient reason for government intervention at the federal level in the U.S. (OMB 2003).

These findings beg the question of whether improvements in policy analysis could help bridge the energy-efficiency gap: are there ways to incorporate firm costs that are absent from typical NPV calculations? The last column of Table 4 presents a few ways that analysts may accomplish this task. For instance, when evaluating firm investment decisions, analysts could use discount rates that reflect the opportunity cost of capital. These rates are typically higher than what is used when evaluating societal tradeoffs due to taxation and other capital market imperfections. Likewise, if the industry puts a premium on certain attributes, such as reliability, then the opportunity cost of giving them up in return for greater energy efficiency should be reflected in policy analysis. Context-specific factors also warrant explicit consideration, including the cost of acquiring information on how an energy-efficient technology will perform in a specific data center.

6. Conclusion

By its very nature, information from focus groups and interviews is not drawn from a representative sample. Despite this limitation, the results may help inform future analyses, surveys, and policy discussions on the drivers of energy-efficient investments in the data center industry. Participants in our study discussed a variety of technologies and strategies to improve energy efficiency at the data centers they manage. As expected, technologies with longer payback periods were not as widely adopted as those that yielded net financial gains within a few years. Many participants looked for a payback of between one and five years,

which is substantially shorter than the equipment lifetime, potentially indicative of an energy-efficiency gap.

While we find some evidence that market failure explanations such as split incentives and imperfect information played a limited role in slowing adoption for participants, these were likely not of a large enough magnitude to justify government intervention to address the energy-efficiency gap. Based on our sample, rival explanations unrelated to market failures such as the cost of acquiring context-specific information, the opportunity cost of capital, or highly valued attributes aside from energy efficiency played a larger role in slowing investment in energy efficiency.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Figure 1.
Participant Use of Energy-Efficiency Enhancing Technologies, by Data Center Size

Table 1.

Sample focus group and interview questions

Where do you gather information on what new equipment, technologies and facility management strategies are available? Do these sources provide reliable estimates of likely energy use? Are there estimates out there that you don't believe? Why?

Can you give one example of a major investment that improved facility energy efficiency? Why this technology or approach? What attributes make it appealing? What factors did you consider when deciding whether to make this investment?

Thinking of all the factors you've mentioned so far that affect your investment decision, how do you weigh them against upfront cost? Are any of them incorporated into an ROI or payback calculation?

Table 2:**Data Center Participant Summary**

		Number of participants	% ^A
Total number of participants (focus groups plus interviews):		34	
Total number of servers in company:	< 2,000	9	26%
	2,000–10,000	2	6%
	10,000–50,000	4	12%
	50,000 +	14	41%
Data center types (not mutually exclusive):			
Cloud/hyperscale		12	35%
High-performance/scientific		6	18%
Colocation/multi-tenant		11	32%
Sectors supported (not mutually exclusive):	Information technology	15	44%
	Banking/financial services	14	41%
	Media/telecommunications	6	18%
	Health care	9	26%
	Education	6	8%
	Other/not specified	9	26%
Location (not mutually exclusive):	One state	7	21%
	Multiple states	23	68%
	International	5	15%
Number of data centers participant manages:	5 or less	16	50%
	6 – 20	13	41%
	21 – 80	3	9%
Average size of data center participant manages: Server room/localized		7	21%
Enterprise/corporate		8	24%
Mega/utility-scale		19	56%
Server replacement frequency:	< 3 years	3	10%
	3–5 years	19	66%
	Varies	4	14%
Major infrastructure upgrade frequency:	< 2 years	10	33%
	5–10 years	6	20%
	10 or more years	8	27%
Third-party audit in last 3 years?	Yes	13	38%
E.E. program participant (e.g. Energy STAR, Green Grid)?	Yes	24	71%

^APercentage based on total number of participants.

Table 3:

Sources data centers use and trust for information on new technologies and energy efficiency

Information sources	Focus groups	Interviews
Manufacturers/suppliers	6/6	7/7
In-house testing	6/6	6/7
Conferences /trade shows	6/6	6/7
Peers	5/6	6/7
Outside contractors & consultants	6/6	3/7
Trade publications & internet	5/6	2/7
Regulators & government	0/6	1/7

Table 4.

Evidence on factors that limit energy-efficiency investments

<u>Potential Contributor to Limited Adoption</u>	<u>Discussed by Participants?</u>		<u>Evidence of limiting adoption?</u>	<u>Evidence of market failure</u>	<u>Potential improvement to policy analysis</u>
	Number of Focus groups	Number of Interviews			
Uncertainty and imperfect information	6/6	4/7	Moderate	Mixed	Include info. on real-world performance and cost to gather it
Split incentives					
<i>Within company</i>	6/6	7/7	Moderate	Mixed	Better account for costs of adoption (e.g., coordination, training)
<i>Colocation facilities</i>	6/6	5/7	Moderate	Mixed	
<i>Firm-contractor</i>	3/6	0/7	Weak	Weak	
Financial constraints					
<i>Limited access to outside financing</i>	0/6	0/7	Weak	Weak	
<i>Opportunity cost of capital</i>	4/6	4/7	Moderate	No *	Use discount rate firms use for decision-making
Tradeoffs with other attributes	6/6	7/7	Strong	No *	Develop methods to explicitly value these tradeoffs

* No is used when a reason for slowed adoption is not due to a market failure, while weak is used to signal that while it is possible slowed adoption could be due to a market failure, we find little evidence that this is the case.