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Utilizing "Big Data" to Improve the Hotel Sector's Energy Efficiency: Lessons from Recent Economics Research

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Abstract

Hotel chains have access to a treasure trove of "big data" on individual hotels' monthly electricity and water consumption. Benchmarked comparisons of hotels within a specific chain create the opportunity to cost-effectively improve the environmental performance of specific hotels. This paper describes a simple approach for using such data to achieve the joint goals of reducing operating expenditure and achieving broad sustainability goals. In recent years, energy economists have used such "big data" to generate insights about the energy consumption of the residential, commercial, and industrial sectors. Lessons from these studies are directly applicable for the hotel sector. A hotel's administrative data provide a "laboratory" for conducting random control trials to establish what works in enhancing hotel energy efficiency.

Keywords

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Introduction

In recent years, applied researchers have accessed large micro data sets providing detailed information on millions of households' monthly electricity consumption and similar data for firms and commercial buildings (Ito 2014; Wolak 2011). Both electric utilities and private companies have provided such "big data" to researchers who often sign non-disclosure agreements that permit new research to be conducted while protecting individual privacy. A residential data set might include information for all owner occupied homes within an electric utility district's service area. Such a data set would include information on the household's monthly electricity consumption, expenditure, a numerical identification number for the household (not its name), and the household's zip code of residence. A proprietary commercial real estate data set might include information on the universe of all big box stores from a chain such as Walmart or Target and will include each store's monthly electricity consumption, expenditure and the location of the store, and a vector of attributes of the store's physical attributes, such as the year built and its square footage.

In this paper, we discuss how "big data" will help to improve the energy efficiency of the hotel sector. We discuss new findings from our own recent research. We sketch out a feasible research agenda based on using a hotel chain's administrative data to create a "laboratory" for evaluating the effectiveness of several different, low cost strategies for increasing overall energy efficiency. Hotel chains are literally sitting on a "gold mine" of valuable data. We seek to demonstrate how it can be used both to reduce operating costs and to increase overall environmental sustainability.

Due to increased access to "big energy data," the academic field of energy economics has experienced a surge of intellectual interest.[1] The direct link between electricity consumption and greenhouse gas production has fueled much of this interest. The global externality challenge of climate change can be partially offset by reducing aggregate electricity demand. Much of the world's electricity is supplied by fossil fuel fired power plants (those using coal or natural gas). The fact that so much of the world's power is created using fossil fuels means that there is a negative externality associated with electricity consumption. The typical coal fired power plant in the United States releases 1,232 pounds of carbon dioxide per megawatt of power generated.[2] Although the social cost of carbon continues to be debated (Greenstone, Kopits, and Wolverton 2013), a conservative estimate is to value carbon dioxide at $35 per

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ton. This means that every megawatt of power that hotels consume is associated with a social cost of 35 × 1,232 / 2,000 = $21.50 of damage to society. As profit maximizers, hotels have strong incentives to try to reduce their operating costs, but hotels face a fundamental trade-off because electricity consumption offers their guests a higher quality experience but the hotel must pay for electricity. Standard economic logic argues that the cost of electricity is a private cost but the hotel has no incentive to internalize the social costs from the greenhouse gas emissions created as the fossil fuel fired electric utility produces the electricity consumed by the hotel. Given the algebra presented above, if a hotel consumes an extra megawatt of power, it will pay for this power but it will ignore the $21.50 social cost it imposes on the environment. This example highlights that if "big data" can be utilized to enhance the hotel sector's environmental performance, a "double dividend" will emerge as the hotel's cost of operations will decline and the environmental damage it imposes will shrink.

In the next section of the paper, we introduce a statistical framework to show how a hotel's administrative data can be used to create a laboratory for achieving energy efficiency gains. The hotel's likely energy efficiency gain depends in part on guests' attitudes toward sustainability in the hospitality industry. Bruns-Smith et al. (2015) find that guests are willing to participate in eco-friendly programs, but the attractiveness of green operations cannot override the traditional considerations of price and convenience. We then review findings from recent work in energy economics that have focused on the residential, commercial, and industrial sectors. We discuss which of these lessons is relevant for the hotel industry.

Using Hotel Electricity Consumption Data to Identify Inefficiency

Electricity consumption for a given piece of real estate (such as a home, a commercial building, a factory, or a hotel) for a given month is a function of a large number of variables that can be grouped into three broad categories. First, there are the physical attributes of the piece of real estate. Where is the real estate located? What year was the capital built? How large is the piece of real estate? A second broad set of attributes focuses on the durables built into the real estate. Such durables play a key role in providing basic services such as lighting, heating, and cooling the building. Finally, there is the day to day functionality of the real estate. How many hours a day is the piece of real estate utilized? How many people live and work in that piece of real estate? What incentives do these individuals face to economize on their electricity consumption? Together, these choices determine a piece of real estate's overall environmental performance. At any point in time, both past choices and current choices together determine monthly electricity consumption. This is not a deterministic relationship. Each day, climate conditions may change and equipment may malfunction. These idiosyncratic shocks also play a role in determining electricity consumption.

In a recent study (Kahn, Kok, and Liu 2015), we have partnered with a major United States hotel chain that has provided us with monthly electricity consumption data by hotel. It is a random sample that covers the majority of their portfolio (more than 70 percent). Our data set includes detailed information on the electricity consumption and expenditure in each month for each hotel. The data also include information on the property address, square footage, number of rooms, year of construction, the hotel market quality segment, type of energy used, monthly occupancy, monthly usage, and expenditure on electricity. The data cover the January 2007 to November 2013 period. For each hotel in the chain, climate data are matched to the nearest weather station by the data provider. We then compute heating degree days and cooling degree days for each month and for each property.

We use these data to estimate multivariate regression models. Define kWh_{ijt} as the aggregate electricity consumption (measured in kilowatt-hour; kWh) for hotel i in state j at month t. Define X_{ijt} as a vector of observable attributes of hotel i in state j in month t. We estimate a series of multivariate linear regressions of the form presented in Equation 1.

$$\ln kWh_{ijt} = State_j + \gamma \cdot X_{ijt} + U_{ijt}$$

Note that the X vector includes time invariant physical attributes of the hotel such as the year it was built and the hotel's quality and size and dynamic variables, such as cooling degree days in that month. In Kahn, Kok, and Liu (2015), we focus on testing for how California hotels perform relative to hotels in the same chain that are not located in California. We test this hypothesis because there is great interest among energy economists concerning whether California's more stringent energy efficiency standards have been effective relative to other states (Levinson 2014a, 2014b). We argue that hotels offer an "apples to apples" comparison that is not achievable using other types of real estate such as residential homes. We test this hypothesis by including a vector of state fixed effects and testing if California has the most negative coefficient relative to other states.

We estimate Equation 1 using ordinary least squares (OLS). In this regression, the error term represents the unobserved determinants of a hotel's electricity consumption in a given month. For example, a hotel's guests that month may watch more television or plug in more electronic devices. The kitchen in the hotel may serve more meals. When we estimate such cross-sectional regressions, we are implicitly assuming that "sorting on unobservables"

Exhibit 1:
The Empirical Distribution of a Hotel Chain's Daily Electricity Usage per Occupied Room.

	2007	2008	2009	2010	2011	2012	2013
1%	15.22	15.92	16.94	15.85	15.42	14.98	15.01
5%	18.87	19.80	20.60	19.27	18.68	18.61	18.24
10%	21.50	22.10	23.14	22.12	21.45	21.46	21.14
25%	27.51	27.55	28.79	28.27	27.14	26.93	26.49
50%	37.06	37.83	39.79	38.58	36.87	35.54	37.40
75%	53.39	56.58	58.38	56.74	54.36	51.43	53.45
90%	76.91	82.291	85.66	82.69	80.85	76.28	75.77
95%	99.99	108.24	111.06	105.79	104.54	100.06	92.84
99%	163.43	170.75	186.06	177.61	175.03	167.09	144.20

is not taking place. If guests in California hotels are systematically different than guests of the same hotel chain in different states, then we would recover a California-fixed effect that represents a mixture of the average hotel's energy efficiency and the electricity consumption habits of these select guests.

In Kahn, Kok, and Liu (2015), we find that California's hotels (all else equal) consume 24 percent less electricity than hotels in the same chain located in small states. California's hotels are the most energy efficient in the nation, and this result persists even when we control for the price of electricity that the hotel pays in its local service area. We also find that full service hotels consume 160 percent more electricity per month than hotels of the same size, occupancy, facing the same climate conditions, and located in the same state. This result highlights the fact that a hotel's quality and its electricity consumption are complements. In a second set of results in which we study within hotel variation in electricity consumption, we document that California's hotels are enjoying the greatest reduction in electricity consumption per occupied room over the 2007 to 2013 time period. Although the average hotel outside of California is experiencing no energy efficiency trend progress over time, the average hotel in California is experiencing 4.8 percent reduction in electricity consumption per occupied room per year. Over the course of a decade, this adds up to a huge effect. We must acknowledge that this nonexperimental research design cannot identify why this differential progress is observed.

In Exhibit 1, we use our hotel chain data to report for each year from 2007 to 2013 the empirical distribution of our hotel sample's electricity consumption per occupied room. As there are twelve months in a year, each hotel appears twelve times in each of the calendar years. For each calendar year, we calculate each hotel's total electricity consumption in the month and divide it by its total occupied rooms in that month. We then form an empirical distribution of these data for each calendar year. Exhibit 1 highlights that there is huge cross-sectional variation in average electricity consumption per occupied room within a hotel chain. The median in 2007 is 1.21 but the ratio of the ninetieth to the tenth percentile is roughly 3.5. This huge variation highlights that there are some hotels with much greater electricity consumption.

We have estimated Equation 1 to test hypotheses related to observable attributes of a hotel at a point in time but an alternative use for estimating Equation 1 is to focus on recovering hotel specific electricity consumption residuals. Define the residual from this regression as Uhat. A large and positive Uhat indicates that a hotel in a given month has much higher electricity consumption than one would predict given its observable attributes (the X vector). Suppose that a researcher has data for five hundred hotels and for each of the hotels, observes it over the course of sixty months. The researcher could average each of the residuals for each of the five hundred hotels and sort them from highest to lowest. The basic logic of "low hanging fruit" suggests that the hotel chain should focus its effort to encourage greater energy efficiency effort at the hotels with the largest positive residuals. In a regression where the researcher has included in the X vector attributes such as climate, the hotel's size and year built and quality, the residual reflects other factors that are harder to observe. In this sense, the residual recovery approach mimics a detective's strategy of looking for clues. For example, suppose that a given hotel tends to have a large residual during the summer months but not for the winter months. This suggests that the hotel's air conditioning system is inefficient. The data analyst could establish this point in seconds without visiting any specific hotel. Based on the hotel data we use in Kahn, Kok, and Liu (2015), we have recovered the hotel specific residuals from a regression based on Equation 1. We find that the hotel residuals are highly positively correlated over time. For example, across our sample of hotels, the hotel residual in the year 2008 has a correlation of .81 with the hotel residual in the year 2011. This clearly indicates that there are highly persistent unobserved features of hotels that are determinants of a specific hotel's high electricity consumption over time.

A hotel chain eager to increase its overall sustainability can focus its efforts on the high electricity residual hotels. Once this subset of hotels has been identified, then the next research step is to identify why the inefficiency exists. In past consulting work with a Western electric utility, Matthew Kahn ran residential electricity consumption regressions similar to Equation 1 and then gave the utility the positive residuals from this regression. The utility focused its energy efficiency outreach on this subset of homes.

Previous hotel sustainability research has used survey methods to study whether the managers of the hotel on the ground are prioritizing energy efficiency. Baloglu and Jones (2015) report results from their 2011 survey of ninety-nine hotel managers of upscale and luxury hotels. Their survey concludes that managers were hesitant to implement efficiency measures whose payback was longer than three years or those that might impair guest comfort. These types of surveys are quite useful and can be combined with the "big data" approach described in Equation 1. A complementary research design would conduct a new survey of hotel managers regarding their views of energy efficiency and their knowledge about achieving such efficiency. By merging the hotel manager's responses to the "big data" (by hotel street address), the researcher could test whether managers who highly prioritize energy efficiency are more likely to have negative residuals based on Equation 1. This would be direct evidence that manager beliefs have implications for actual "hard" sustainability metrics. If a strong correlation is observed, then the hotel chain could invest resources seeking to help managers better understand the trade-offs they face between electricity conservation and delivering a quality guest experience.

The Role for Experimentation and Economic Analysis

Economic analysis is relevant for helping a hotel achieve the joint goals of minimizing operating costs while offering a high quality guest experience. Susskind (2014) conducts a study of 192 independent four-star hotel guests. This study argues that hotels are able to save cost and improve sustainability by saving energy without diminishing guest satisfaction. Such a hotel will face a set of choices and trade-offs. Using the administrative electricity data as a baseline diagnostic tool (after estimating a version of Equation 1), the hotel leadership can think about how to design incentives to encourage greater conservation by individual hotels. For example, for hotels located in geographic areas where electricity is priced low, does the chain value energy efficiency? If the chain is focused on reducing operating costs, then the most attractive hotels for focusing randomized control trials will be those with a high residual where the price of electricity is high. These are the hotels whose operating costs would fall the most if improvements in efficiency could be achieved.

In recent years, economists have launched some ingenious field experiments in which a randomized control trial approach is used. A hotel chain could follow this same strategy. To provide a simple example, suppose that the hotel chain believes that a performance bonus offered to the manager and tied to reducing energy consumption relative to a baseline would reduce hotel energy consumption. The hotel chain could focus on the subset of hotels with a high residual based on Equation 1 and randomize this subset of hotels into a treatment group and a control group. For the 50 percent of the sample hotels randomly assigned to the treatment group, the manager in charge of energy could receive the incentive notification. He or she would be informed about what criteria would be used to judge whether the bonus would be paid out. For example, the criteria might offer \$$X$ as a bonus if a Z percent reduction in electricity consumption is observed in a specific month relative to the electricity consumption in the previous year during the same month. For the control hotels, their managers would receive no new communication. The hotel chain would then implement this incentive system and collect new monthly data for the set of treated hotels and control hotels. After a certain amount of time, such as twelve months, the hotel chain could run the following regression (Equation 2):

$$\ln kWh_{ijt} = a + \gamma \cdot \text{Treatment Group}_{ijt} + U_{ijt}$$

In this regression, Treatment Group is a dummy variable that equals 1 if the hotel was randomly assigned to receive the incentive and equals 0 otherwise. By the definition of random assignment, the error term is uncorrelated with the explanatory variable. Randomization removes any concerns about selection bias (that the subset of hotels that chose to take the treatment differ on unobserved features so that there is an "apples and oranges" problem). With successful randomization, any average differentials between the treatment group and the control group must be due to a treatment effect enjoyed by the treatment group. Without successful randomization, the fear will always lurk that any ex post differences between the treatment group and the control group are due to selection.

The key hypothesis of interest is to test whether γ is negative and statistically significant. If so, this is evidence that this treatment is effective. A more subtle analysis would try to quantify the treatment's "bang per buck" by calculating the monthly dollar benefit of this treatment. This can be calculated by multiplying the price of electricity times the predicted reduction in electricity consumption. An economic analysis would compare this cost savings brought about by the treatment while netting out the cost of paying out the bonus incentive. An even more subtle analysis would study guest satisfaction surveys to see if guests in the treatment group hotels gave those hotels lower ratings as the experiment played out. For example, if the manager chooses to reduce air conditioning access in the summer, then the guests will suffer, but the manager will earn a larger bonus. Such perverse effects need to be anticipated before launching such an experiment. One solution would be to tie the bonus to both energy efficiency and guest satisfaction.

A key point to note here is the modesty of the hotel chain that participates in such an experiment. The hotel chain's leadership must admit that it "knows that it does not know" what is the right incentive approach for reducing electricity consumption. Its chief executive officer (CEO) must be willing to launch experiments that may sometimes ex post turn out to not be effective. Note the key role the administrative data play here. Without the administrative data, there would be no way to conduct a valid "before/after" comparison for the treatment and control hotels. The data from individual hotels within a chain have to be collected in a standardized format so that they can be evaluated using basic statistical method.

In this last section, we have sketched out an ideal partnership between a hotel chain and academic researchers. Researchers who have been able to access "big data" have rarely been able to launch a randomized field experiment and then use the data to have a baseline for the treatment group and the control group. To appreciate this point, we will now discuss recent lessons learned from residential, commercial, and industrial "big data" and then return to hotel field experiments. In each of the next three sections, we will compare and contrast each of these real estate sectors with the hotel sector.

Energy Efficiency Insights Based on Big Data Analysis of the Residential Sector

Based on data from the U.S. Energy Information Administration (EIA; see http://www.eia.gov/consumption/), the residential sector consumes (as of 2014) 27.4 percent of total U.S. energy consumption, the commercial sector consumes 19.4 percent, the industrial sector consumes 29.4 percent, and the transportation sector consumes 23.8 percent. These statistics highlight the roughly equal importance of all of these sectors, but the bulk of academic energy research has focused on the residential and transportation sectors.

In the United States, there are 133 million housing units.[3] The majority of these housing units are owner occupied units. Although homeownership has many admirable benefits (and also certain well known tax advantages), it must be acknowledged that it often places an "amateur" as the key decision maker in making a variety of decisions that affect a home's electricity consumption. For example, homeowners are unlikely to know how their daily activities such as watching television or leaving on the lights translates into much higher electricity consumption. They rarely know how much money they would save per year by purchasing a more energy efficient air conditioner (Wolak 2011).

Millions of energy inefficient homeowners add up to sectoral inefficiency. There is no reason to believe that a homeowner is aware of how much money he would save by making any one of a number of energy efficiency investments. To calculate such a cost savings, the homeowner would need to be aware of how his day to day activity determines his electricity consumption and then be aware of how the local electric utility bills him for electricity consumption. As documented by Ito (2014), the typical southern California household does not understand marginal pricing or the increasing block tariff structure that he faces. In an ingenious research design, Ito (2014) studies household electricity consumption for homes close to each other but that are located in different electric utility districts. These adjacent utilities charge different prices for electricity and Ito exploited this variation using a regression discontinuity strategy and concludes that households respond to average prices, not marginal prices, in determining their monthly consumption. Kahn and Wolak (2013) offer an explanation for this finding. They implement a field experiment by teaming with a Western electric utility. They offered a financial payoff to a random set of households to participate in a 20 min internet education course. During this brief internet interaction, they taught households about the nuances of the increasing block tariff (i.e., that the marginal price of an extra kWh rises at discrete steps). Using data on each household's electricity consumption in the summer before the field experiment, Kahn and Wolak (2013) identified households who faced a high marginal price for electricity. For the subset of these households that took their treatment, this subset sharply reduced their consumption after taking the treatment (and learning the specifics of marginal pricing). This research highlights that providing consumers with real time information (perhaps using cell phones) can incentivize efficiency.

In the United States, the typical residential household faces a monthly electricity bill of $111.[4] This relatively low outlay means that households are not "leaving that much money on the table" by not being experts on energy efficiency. Wolak (2011) introduces a cost of action model in which households incur a cost to take energy efficiency actions such as swapping out windows or installing insulation. In his model, households will only make these investments if the cost savings from doing so exceed the household's cost of action. His model predicts ranges of "inaction" in which households do not make investments that a business would calculate as having a positive expected present day value (PDV). The important point to note here is that this is not a behavioral economics model of people making mistakes (Thaler 2015). Instead, people are aware that taking an action is costly for them, and they will only take the action if the benefits of the action exceed this cost.

Nudges

The recognition that households need to be "nudged" to focus on energy efficiency has been the basis for a very successful company called Opower. This company has sought to reduce the electricity consumption of households by providing them with customized home energy reports. In receiving these tailored reports, a household sees a user friendly graph of its electricity consumption over the last twelve months and how its consumption compares with its 100 closest neighbors and its twenty most energy efficient neighbors. To construct these reports, Opower partners with the electric utility and geocodes all of the homes to establish the peer comparison group for each home. In a series of papers, Hunt Allcott has evaluated the consequences of such reports and the conditions when they are most likely to change household behavior (Allcott 2011). Recent hotel research has examined the question of whether such nudges could change hotel guest behavior. Huh and Lee (2015) discuss the fact that guest-driven sustainability nudge campaigns have so far only encouraged guests to participate in towel and linen reuse, and in recycling. Based on their survey, they are optimistic that such nudges could achieve some environmental gains at hotels. Water conservation nudges at hotels have proved to be effective (Goldstein, Cialdini, and Griskevicius 2008).

Split Incentives

Hotels and multifamily apartment rental buildings share a common characteristic that there is a split-incentives problem. In the case of residential housing, researchers such as Levinson and Niemann (2004) have documented that renters who do not pay their own utilities and thus face a zero marginal cost for consumption, consume more electricity than those renters who pay their own bills. If renters do pay their own electricity bills, then this creates weak incentives for the apartment building owner to install energy efficient durables such as windows or air conditioning systems. This pessimism would be countered if a building's energy efficiency was an easy to quantify metric. For example, with new vehicles, they are required to post their miles per gallon to benchmark their fuel economy. Up until now, apartment buildings have not faced such disclosure rules. If this information were commonly known, then more energy inefficient buildings would feature lower rents because potential tenants would anticipate that they would face higher electricity bills if they choose to live in such buildings. Hotels also face this split-incentives issue because guests are not charged for water or electricity. A field experiment design could be used to test if incentives of offering a hotel room bonus for conservation could encourage conservation. Up until now, hotels have relied on nudges to try to encourage guest conservation (Goldstein, Cialdini, and Griskevicius 2008).

The Economic Returns to Green Real Estate

Energy efficiency may offer economic values to hotels both through lowering operating costs and by conveying quality and a commitment to environmental protection. Recent research on green residential real estate offers some optimistic findings. Brounen and Kok (2011) present results from home sales in Holland. This nation has introduced an energy efficiency rating system. They report evidence that more energy efficient homes enjoy a price premium. The Dutch energy ratings system resembles a school report card with letter grades of "A," "B," and "C." In another study, Kahn and Kok (2014) document that California homes that are Energy Star certified sell for a 4 percent price premium relative to observationally identical homes on the same street in the same zip code that sold in the same time period. Recent research has also documented a price premium for solar homes. Dastrup et al. (2012) use home sales from San Diego and Sacramento counties and estimate a 3.5 percent solar price premium. They document using repeat home sales data that for homes that do not yet have solar panels (but will have them installed in the future) that this subset of homes do not sell for a price premium but they do sell for a price premium once they install solar. This evidence reduces concerns of selection bias effects that the solar price premium is due to unobserved other attributes (attributes the researcher does not observe) but that the potential home buyers do take into account. This residential research raises questions about the resale value of hotels. Do hotels with green features (solar, Leadership in Energy and Environmental Design [LEED] certified) sell for a price premium? Do they charge a hotel guest premium? Research by Eichholtz, Kok, and Quigley (2009, 2010) provide evidence supporting the hypothesis that Energy Star certified commercial real estate also rents for a price premium. In their 2010 study, they document the type of tenants who are most likely to demand to locate in such properties.

Recent hotel research presents a more mixed message. Chong and Verma (2013) find that eco-certified hotels have neither higher nor lower booking revenue based on millions of individual bookings in more than three thousand eco-certified hotels and a comparison group of six thousand properties. Their research includes any hotels that have earned environmental certifications, including LEED and Energy Star as eco-certified hotels. In 2014, Walsman, Verma, and Muthulingam focus on hotel performance of LEED certification, which is a green buildings standard that has gained considerable acceptance since 2000. They find that, on average, the ninety-three certified hotels obtained better financial performance compared with their 514 non-certified competitors.

Climate Change Causing Rising Summer Heat

Using "big data," several research teams are exploring how the residential sector's electricity consumption responds to summer heat. In this line of research, researchers augment a regression model such as Equation 1 to include monthly climate variables such as cooling degree days. They seek to test how much more electricity does the hotel consume on a hotter day in July relative to April. After estimating such regressions, such researchers then use climate change models to predict how different cities' summer heat is likely to change. By combining the climate change model with the econometric estimates of how homeowners respond to summer heat, researchers predict how climate change will affect residential consumption of electricity (Miller et al. 2008). Such research could also be conducted for the hotel industry using regressions of the form presented in Equation 1 in which the X vector would include a polynomial in monthly cooling degree days. For a survey on the issue of how electricity consumption will evolve in the face of climate change, see Auffhammer and Mansur (2014).

Energy Efficiency Insights from the Commercial Sector

The Energy Information Agency predicts that between the years 2005 and 2030, residential electricity consumption will increase by 39 percent, industrial consumption will increase by 17 percent, and commercial electricity consumption will increase by 63 percent.[5] Such increased consumption will have significant greenhouse gas externality consequences.

Given that commercial buildings are often operated by for-profit managers, this sector is likely to be more responsive to economic incentives for energy conservation relative to the residential sector, where households have been found to exhibit behavioral biases that sometimes discourage making cost-effective energy efficiency investments (Allcott, Mullainathan, and Taubinsky 2014).

To study the determinants of commercial real estate electricity consumption, Kahn, Kok, and Quigley (2014) partnered with a major electric utility and merged information on electricity consumption at the building level with detailed physical attributes of the building. They document that higher quality real estate consumes more electricity. They also document using a regression framework similar to Equation 1 that buildings with a high percentage of tenants who do not pay their electricity bills consume more electricity than buildings where tenants pay their own bills. This differential grows when it is hotter outside.

Energy Efficiency Insights from the Industrial Sector

A major research topic in modern economics is the study of productivity differentials of firms within a narrowly defined industry (Syverson 2010). One line of research focuses on the causal role of management quality and variation in such quality as a key explanation for why some observationally very similar firms differ greatly with respect to their profitability and productivity. Although this hypothesis is intuitive, it is very difficult to test because of the challenge of ranking "manager quality" both within firms and across firms.

In an ingenious set of research studies, Bloom et al. have created a metric based on interview survey technique to rank managers with respect to their quality. To measure management practices, they use an interview-based evaluation tool that defines and scores from one ("worst practice") to five ("best practice") across eighteen basic practices. The evaluation tool scores these practices in three broad areas: first, monitoring: how well do companies track what goes on inside their firms, and use this information for continuous improvement? Second, target-setting: do companies set the right targets, track the right outcomes, and take appropriate action if the two do not tally? Third, incentives: are companies promoting and rewarding employees based on performance, and systematically trying to hire and keep their best employees?[6]

They have matched these management data to information on energy intensity to examine the relationship between good management and energy efficiency. They have collected data for a set of British manufacturing plants for which they observe the plant's energy intensity, which is defined as energy consumption per dollar of value added and their metric of management quality. In Bloom et al. (2010), they document that better managed firms are less energy intensive. Although it is difficult to establish causality here, this is a very optimistic result. Human capital and better management offers the possibility that a well-trained manager can oversee the efficiency of many different hotels at the same time. An important hypothesis to test would be to study whether larger hotel chains are more energy efficient than smaller hotel chains and single hotels. Larger hotels control more square feet of real estate and, thus, have the incentives to hire specialists whose ideas can be implemented at more hotels. Such scale economies would mean that industry mergers would actually accelerate energy efficiency gains.

Large-scale Randomized Field Experiments Can Enhance Hotel Energy Efficiency

In an earlier section, we sketched out a statistical research design that can be used for testing for the causal effects of new energy efficiency ideas. The key for testing whether a given "treatment" is cost effective is to engage in successful randomization of hotels to a treatment group and a control group at the baseline. Such randomization guarantees that, on average, the treatment group and control group were identical at the point in time before the experiment began. This means that at the baseline, the average consumption of electricity for hotels in the treatment group will not be statistically different than the average consumption of electricity for the control group.

A researcher who successfully achieves this randomization and then has access to data indicating each hotel's subsequent monthly electricity and water consumption can then estimate Equation 2 to determine which treatments are effective in encouraging conservation. One nuanced point is that the experimental design is more likely to be effective if individual hotels are unaware that an experiment is taking place! If individual hotel managers speak to each other and learn that some hotels are facing different incentives than others, then this may change their behavior in unpredictable ways. The goal of the field experimenter is to expose an economic agent to a new set of rules and to see how they respond as they face these "rules of the game" while having access to a control group of similar economic agents who face the "old rules of the game." This experimental design is needed because there is a fundamental missing data problem. For hotels invited to be exposed to a given treatment, the analyst never observes what their energy consumption would have been had they not been invited to participate in the treatment. The control group's behavior helps to solve this counter-factual challenge.

Here, we list some feasible field experiment designs. The research goal here is to identify potentially cost-effective treatments that would significantly increase a hotel's energy efficiency without sacrificing the quality of the guest's experience staying at the hotel.

Example 1: A hotel chain could offer incentives to a random sample of guests in a hotel on specific days to encourage water and electricity conservation. The control group could be consumption on the same day of the week at the same hotel the following week.

Example 2: The hotel chain could randomize a subsidy to offer to different hotels to upgrade durables in the hotel. This research design would yield insights about the probability that a given hotel manager chooses to upgrade the durables and an estimate of the energy savings from doing so. A similar strategy could be tested for installing solar panels on the roof.

We do not claim to have a monopoly on good ideas for achieving greater energy efficiency in the sector. One of our main optimistic points is that the administrative data that hotel chains have access to create a laboratory for testing ideas such as these.

Conclusion

In mid-2015, the United States is unlikely to enact a carbon tax in the near future. In the absence of such a policy, electricity consumption (especially in regions that produce much of their power using coal and natural gas, such as the Midwest) will continue to translate into large amounts of greenhouse gases. This logic highlights the social environmental gains from hotels pursuing greater energy efficiency. Such hotels gain lower operating costs but it remains an open question concerning how much guest services quality is sacrificed by consuming less electricity. For example, if heating, ventilating, and air conditioning (HVAC) systems are less heavily used on a hot day, electricity declines but guests are less comfortable. Hotels must balance such private benefits of electricity consumption against the private costs of increasing electricity consumption and purchasing more energy efficient but costly durables.

This paper has presented an optimistic overview of how electricity "big data" can be used to create a laboratory for allowing major hotels to study their own energy efficiency dynamics. Fruitful partnership between engineers and economists are likely to yield tangible results. Although engineers have expertise in systems efficiency, economic analysis yields a more nuanced understanding of how to design incentive contracts and monitoring systems to reward efficiency without going too far and diminishing the quality of the guest's experience. Human capital and expertise in energy efficiency opens up the possibility of the hotel sector achieving improved environmental performance.

As academics, we seek to partner with hotel chains who "know that they do not know" how to achieve energy efficiency gains and are willing to try experiments to yield improved performance. This scientific approach to experimentation has achieved notable results in many developing countries (Banjeree and Duflo 2011), and we are optimistic that similar results can be achieved in the hotel space.

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Notes

1. The National Bureau of Economic Research has created a full program on Environmental and Energy Economics. The working papers for this group are available here: http://www.nber.org/papersbyprog/EEE.html.
2. http://www.epa.gov/climateleadership/documents/emission-factors.pdf.
3. https://research.stlouisfed.org/fred2/series/ETOTALUSQ176N.
4. http://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf.
5. See page 82 of the U.S. Energy Information Administration's Annual Energy Outlook 2007 With Projections to 2030. ftp://tonto.eia.doe.gov/forecasting/0383(2007).pdf.
6. http://www.voxeu.org/article/modern-management-good-environment-or-just-hot-air.

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