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Enabling Innovation In The Energy System Transition

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ENABLING INNOVATION IN THE ENERGY SYSTEM TRANSITION

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ABSTRACT

Innovation in the electric sector has the potential to drive job growth, decrease environmental impacts, reduce rate payer costs, and increase reliability and resiliency. However, the traditional electric system was built to deliver a controlled flow of energy from a centralized location with maximum reliability and minimum cost. As both customer expectations and generation technologies change, new avenues for grid innovation are being explored. Residential customers, commercial and industrial clients, and electric utilities must all find a way to balance goals for decarbonization and social justice with maintaining a least cost, reliable power grid. Grounded in Geel's energy system transition framework, this dissertation explores how each of these three stakeholder groups is navigating the transition to renewables.

The first study tests the idea that residential customers will be more inclined to change their behavior when altruistically contributing to a greater goal. Renewed Darwinian theory was explored to question the exclusive use of financial incentives in demand response programs. A difference in differences approach was designed to test the impact of the Burlington Electric Department's Defeat the Peak program on residential energy use where the incentive was a group donation to a local charity. Results suggest utility savings of over $12 in energy supply costs for every $1 they invested in the program.

Financial levers, however, can be quite effective in influencing electricity demand, and may result in cost-shifting from high to low demand consumers. The second study focused on rate design for commercial and industrial customers through an analysis of the utility demand charge. Under the current system, most small commercial and residential customers do not receive a strong direct price signal to invest in storage, load shifting, or renewables. Larger commercial and industrial customers exercise some measure of control over their loads to reduce demand charges, but with only modest benefit or value to the system as a whole. The system costs are then redistributed to all customer classes, potentially falling disproportionately on low demand customers. To investigate, a regression analysis was conducted with cost and market characteristics from 447 US electric utilities. Results suggest that demand charges predict a significant degree of variability in residential pricing, confirming suspected cost shifting. Redesigning the demand charge could open up new markets for renewable energy entrepreneurs and lower grid costs and customer rates, supporting goals of decarbonization while also achieving reliable least-cost power.

In the third study, an iterative approach was employed to understand why some utilities lean into the energy system transition while others take a more conservative stance. A database of 170 US electric utilities was constructed including a qualitative assessment of Integrated Resource Plans for renewability orientation. Institutional resource-based theory was utilized to take a striated approach to understanding firm heterogeneity, identifying factors at the individual manager level, firm level, and external environment that can influence a utility's energy supply characteristics. Independent variables in a simultaneous regression analysis included CEO gender and tenure at the individual level, ownership structure and firm age at the firm level, and the impact of policies and state rurality at the inter-firm level. Results indicate that a significant amount of a utility's commitment to the renewable energy transition can be predicted based on these firm characteristics.

CITATION

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DEDICATION

I want to dedicate my dissertation to my daughter Scarlet who believes most of what I say without the need for any references and has been a source of unwavering love and confidence throughout this process.

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Innovation in the Energy System Transition

The decarbonization of the United States energy system will deeply impact social justice goals, the pace and severity of climate change, and the ability of the American economy to compete on the world stage. In its current manifestation, the US electric grid represents a narrative of centralization where a small number of people control a small number of generators that provide affordable and reliable electricity to the American public. Unfortunately, the power produced through this fossil-fuel intensive system is only affordable in the short term. The long term ramifications of fossil fuel extraction, transportation, and consumption are only beginning to make themselves clear. Amidst a backdrop of increasingly frequent severe weather events, widespread droughts, and rising sea levels, the time for rapidly changing the energy system is long past due (IPCC, 2018). As the social, environmental, and economic costs of unconstrained pollution becomes increasingly severe, pressure on the existing system has intensified.

The necessary energy system transformation presents a dramatic opportunity to mitigate the environmental impact of our energy choices as well as restructure the decision-making authority that currently directs energy siting, generation, distribution, and ultimate end uses. Community organizers are navigating new paths forward that empower and include a far broader range of groups and individuals in energy-related decisions (Burke et al., 2017). The historical theme of centralization is becoming disrupted as more stakeholders take control of their energy generation and consumption, forcing themselves into a marketplace that was once the sole purview of established generation utility executives and corporations (Stephens et al., 2015). Priorities for the electric grid are also shifting from short-term financial benefits to long-term social, environmental, and economic benefits.

Despite this shift in priorities, the energy system transition is not occurring quickly enough. The Intergovernmental Panel on Climate Change (IPCC) released a special 2018 report to address growing concerns over catastrophic climate change if greenhouse gas (GHG) emissions are not drastically and immediately curtailed (IPCC, 2018). The actions of the United States in particular, the largest greenhouse gas emitter in history, are critically important in achieving significant reductions in GHG emissions. The United States produces 21% of the world's carbon dioxide emissions, and 98% of those emissions are attributed to energy consumption (Attari et al., 2010). Severe weather events and changing seasonal weather patterns are already disrupting food systems and destroying critical infrastructure, compounding pressures that can result in the displacement of large populations and widespread human migration (Black et al., 2011; Farbotko and Lazrus, 2012; Farbotko and McGregor, 2010; McGregor, 1994). As the social and environmental costs of the existing energy system continue to compound, it is critically important to examine drivers of change that could bring about a more sustainable, socially just, and economically viable power infrastructure.

In response to these global challenges, new technologies to generate, store, and control energy consumption are emerging and motivating an empowered and engaged citizenry. In the US alone, between 2006 and 2017, solar experienced an annual growth rate of 54% and an increasing amount of this new electricity generation is owned by non-utility generators (Schittekatte et al., 2018; SEIA, 2018; Van der Kam et al., 2018). However, despite this growth, only 35 billion kWh of energy was produced from small-scale solar (less than one MW of electricity generating capacity) in 2019, less than one percent of all energy generated in the US that year (US EIA, 2020). In total, renewable energy (including solar, wind, hydro, biomass, and geothermal) was responsible for 17% of US energy generation in 2019 (US EIA, 2020). Notably 38% of the renewable energy total is from large hydropower, a centralized generation technique with significant environmental challenges that limit its further expansion (Liu et al., 2013; Xingang et al., 2012; Zia et al., 2011). If decentralized, distributed renewable generation is to become possible, new supporting technologies and services need to be developed and implemented. In order for the existing fossil-fuel regime to be displaced, viable alternatives must exist. A key question that emerges, then, is what will it take to develop these renewable technologies and provide for much more significant market penetration?

This dissertation focuses on renewable energy entrepreneurship as a central feature to technology investment, development, and expansion. The approach of this research is to examine one or more key themes of the renewable energy system transition in each of three studies, recognizing the dual importance of achieving both social and technical goals for the grid. Through this dissertation, the following three interdependent questions are addressed:

1. Can pro-social engagement strategies effectively motivate residential customers in the energy system transition?

2. Can the existing commercial and industrial demand charge rate structure support a decentralized grid without limiting innovation or unfairly allocating costs to residential customers?
3. Why are some utilities leaning into the renewable energy transition while others follow a more conservative approach?

1.1 Sociotechnical Transitions

There is a wealth of literature on the diffusion of technology and on the sociotechnical transitions that transformative innovation can engender. For instance, Markard et al. (2012) refer to four key approaches in the literature for understanding how sustainability transitions occur: strategic niche management, technology innovation systems, transition management, and Geels' multi-level perspective. Strategic niche management seeks to understand why some new ideas flourish and grow within niches while others fade into obscurity (Smith and Raven, 2012). The focus on niche level new technology is also a defining characteristic of technology innovation systems for the purpose of identifying drivers and barriers to innovation and providing policy recommendations (Markard et al., 2012). Researchers who apply this framework employ concepts like economic competence, clustering of resources, and institutional infrastructure in order to understand how new technologies develop and gain acceptance (Carlsson and Stankiewicz, 1991).

The transitions management literature has its roots in complex systems theory, and conceptualizing management as an adaptive and evolutionary process (Markard et al., 2012). In this framework, governments must take an iterative and reflexive approach to support sustainability transitions to help avoid path lock-in and support regime changes (Kemp and Loorbach, 2006). Finally, the classic multi-level perspective introduced by Geels is perhaps the most popular. It divides the socio-economic environment into three levels: niche, regime, and landscape. The interplay of dynamics between and within these levels informs the pace and promise of sociotechnical change (Geels, 2005).

These frameworks all offer a different perspective into the complex world of sociotechnical change. They differ primarily in terms of the audiences for whom their work is addressed and their focus on technology, government, social institutions, and the interplay between them. Frank Geels (2005) approach has emerged as one of the most prominent transition frameworks and was thus selected as the model upon which to base this dissertation.

1.2 Today's Energy System Transition

Energy systems worldwide are currently transitioning to a new regime as the nature of key industry resources changes and social movements and policy changes destabilize established organizational fields. In the US, new grid priorities like decarbonization require systemic changes that threaten the business model and existing revenue streams for electric utilities (Woolf et al., 2014). This type of seismic shift that involves both behavioral and technological adaptation has been studied extensively. Geel's multi-level perspective (Figure 1.1) organizes the types of changes that are occurring into three different levels and helps guide a discussion of the complex factors at work in the energy system transition.

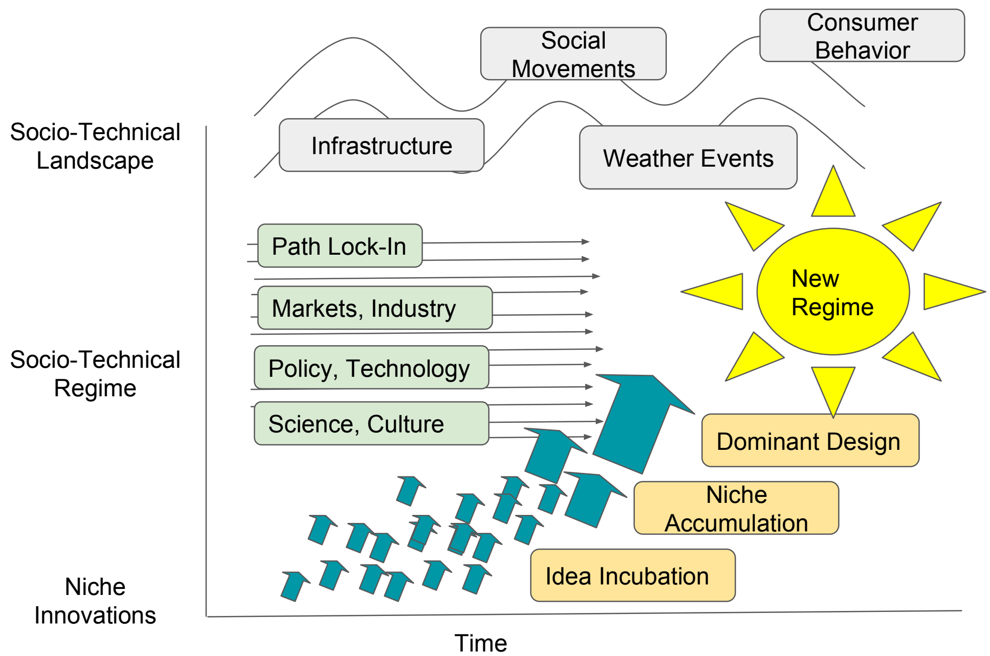

Figure 1.1. Themes in the energy system transition (Geels, 2005).

The first level of Geels' framework is the protected niche where new innovations can develop and eventually challenge and replace the existing sociotechnical regime (Geels, 2005). The protective space of a niche is critical because path-breaking innovations are unable to compete within the selection environments of existing sociotechnical regimes (Smith and Raven, 2012). In the case of the energy industry, innovations like solar and storage need to be protected in order to overcome technical challenges and achieve sufficient economies of scale to compete with embedded centralized generation (Adil and Ko, 2016). Niche construction can be understood through three perspectives on environmental construction, including coevolution, cognitive, and political action (Luksha, 2008).

In the coevolution perspective, evolving entities and their environments are mutually shaped by one another in the niche state. An organization will change its environment and environmental conditions will shape the development of the organization. Alternatively, the cognitive perspective is rooted in phenomenology, or perhaps even solipsism, and claims that an organization's environment is invented by the organization itself. This perspective can be taken to extremes, denying the existence of an external environment and thus the assumption that an organization would need to adapt based on external factors. The final perspective is one of resource dependence and political action, where struggles for power shape the conditions of an organizations existence (Luksha, 2008). What all of these niche-level approaches have in common is the shared belief that new transformative technologies must develop in protected spaces in order to succeed. In the energy industry, electric utilities are often the only customers that can test new technologies. The willingness of an electric utility to support the development of niche technologies is thus critically important to the pace and, ultimately, the success of the energy system transition.

The next level in the multi-level perspective is regime, where existing stakeholders and policies face pressure from both the niche level and from broader sociocultural trends. Electric distribution utilities represent one of the primary stakeholders in the existing regime as they face pressure to incorporate niche-level innovations while also responding to broader, societal level changes. This type of pressure on the regime is referred to in the institutional entrepreneurship literature as disintermediation, or creative destruction, and occurs as the result of an institutional shift (Ritchie and Brindley, 2000). An institutional shift is the moment when an industry's existing rules for competition are changed as a consequence of new regulatory frameworks, technology standards, or business models (Bohnsack et al., 2016). In the energy industry, all three of these elements are changing as a result of the increased prioritization of grid decarbonization.

In the traditional business model, electric utilities receive a guaranteed rate of return on their investments in energy infrastructure, drastically reducing the financial risks of investing in traditional energy generation and transmission technologies. Niche level innovations and the trend of customer ownership of generation resources is disrupting that revenue model. Distributed generation systems like peaking plants, micro-generation and combined heat and power are giving customers an enhanced ability to generate and control their own energy, putting pressure on the existing electric utility business model by curtailing a previously reliable revenue stream (Carley, 2009). The 'used and useful' clause makes investment in niche level technologies extremely risky, as utilities need to prove that the economic value is higher than the accounting cost in order to pass through the cost (Brunekreeft and McDaniel, 2005). If a utility supports a niche level testing project and the savings do not materialize, the utilities will not be reimbursed for their investment. Not all electric utilities are willing to risk their rates of return on a new renewable technology or to support their customers as they invest in generation infrastructure that diverts utility revenue streams. Nevertheless, some utilities are leaning into this new entrepreneurial landscape and actively working to support niche technologies and services.

The third level of Geels' multi-level perspective describes the sociocultural trends that push the existing regime to change. In the energy industry, social concern for the environment can influence utility perspectives and actions in different ways. The literature on social entrepreneurship emphasizes the importance of social movements and collective action in the successful formation of new institutions. Social movements are particularly important in situations where normal incentives are inadequate to create public goods, or when market mechanisms are inadequate to reduce negative externalities like pollution (Rao et al., 2000). In these situations, market mechanisms are inadequate to effect necessary changes in the sociocultural regime and the organization of social actors around a common cause can be deeply impactful.

Social movements can catalyze institutional entrepreneurship in three key ways: motivating entrepreneurs, creating market opportunities, and providing supporting infrastructure (Tolbert et al., 2011). Social movements motivate entrepreneurs by influencing the cultural conversation and creating new value paradigms. By labeling certain fields as virtuous, aspiring entrepreneurs can be inspired to take risks outside of purely financial considerations. While this might not be the explicit intention of a social movement, the mere act of changing the underlying value of certain activities can be extremely impactful. For example, one entrepreneur in the wind industry was challenged by his daughter to “do something in his life as worthwhile as developing renewable energy sources” (Asmus, 2001), as cited in (Tolbert et al., 2011). Another effect of social movements is the creation of new market opportunities. Demand for products that are sustainable and efficient are driven by the value set espoused by various social organizations. By persuading individuals that their purchasing decisions can be aligned with social values, the market dynamics can shift and a new group of products and services can emerge that often benefit from premium pricing allowances by consumers (Lee, 2009).

Infrastructure is another driving force in Geels' sociocultural level. In the US energy system, infrastructure is decaying and in need of massive investment (Adil and Ko, 2016). Blackouts are increasingly frequent, raising concerns related to security and public welfare (Dedrick et al., 2015). Events like the California Camp Fire that contributed to a major investor owned utility, Pacific Gas and Electric, declaring bankruptcy are forecasted to become increasingly commonplace (Sullivan et al., 2019). Physical changes in the environment are also putting pressure on the existing power regime.

Electric utilities and other regime actors are facing pressure to change from multiple angles and Geels' multi-level perspective adds structure to the complex dynamics underlying the energy system transition. Niche innovations are becoming cost competitive with existing fossil fuel technologies, but the distributed nature of generation and risks related to the used-and-useful clause make these innovations difficult to reconcile with the existing utility business model. At the sociocultural level, aging infrastructure and increased demand for decarbonization are further threatening the established stakeholders in the power industry. As the supply and demand characteristics of the electricity marketplace evolve, stakeholders need to make complex decisions about resource acquisition, social engagement, and niche innovation.

1.3 Levers of Change in the Energy System Transition

The remainder of this dissertation explores elements of social and technical innovation in the energy system transition. In the first paper, social innovation is investigated through inter-disciplinary research on altruistic behavior, weaving together insights from evolutionary economics, renewed Darwinian theory and behavioral economics. The pro-social engagement strategies that emerge from the literature are tested and quantified in a difference-in-differences model. The second paper acknowledges the critical nature of financial incentives, particularly for commercial and industrial customers. A deep dive into the demand charge rate structure raises questions about the ability of existing rate structures to fairly allocate costs in a decentralized grid. The final paper analyzes the variability in environmental consciousness between distribution utilities. By applying theories from entrepreneurial orientation and the institutional resource-based perspective we developed a rating system to assess the entrepreneurial orientation and environmental consciousness of US electric utilities. The following places the body of work within the larger context of market opportunities and challenges to be overcome as the grid evolves into something new.

1.3.1 Defeat the Peak: Non-financial Strategies for Stakeholder Engagement

A successful energy system transition will go beyond substituting renewable technologies for fossil fuels. Social decentralization is a key piece of this sociotechnical transition, and in order for this to occur a more diverse set of stakeholders needs to be invited to participate in decisions related to energy siting and distribution. The literature on behavioral economics, evolutionary economics, and renewed Darwinian theory presents new paradigms for human behavior that could be leveraged to create deeper and more effective engagement strategies (Lawrence and Nohria, 2002a; Thaler and Sunstein, 1999). This analysis found that the nature of that invitation is critical, and that pro-social appeals to residential customers can be at least as effective as financial incentives. By analyzing the impact of a demand response program in Burlington, Vermont over the summer of 2017 we were able to demonstrate a high rate of return on a pro-social program. Our difference-in-differences model provided a measurement template for utilities considering new approaches for actively managing their peaks and collaborating more closely with their customers.

1.3.2 Rate Design for Social, Economic and Environmental Success

Rate structures that were designed over a century ago are perpetuating a centralized electric system based on fossil fuels. The demand charge rate structure provides little financial incentive for small commercial and industrial customers to invest in load shifting technologies, assuring that the demand for distributed storage and generation technologies remains weak. The economics literature and ratemaking best practices from influential thinkers like (Bonbright et al., 1961) provide a background story for demand charges, detailing how and why they evolved to help utilities recover costs related to demand. The demand charge rate structure has persevered for a century despite the changing needs of grid operators and customers. The context of the late 19th century is considerably different from today's reality as generation increasingly fluctuates with weather and consumers ask for more complicated services from the grid such as charging for electric vehicles or the ability to sell solar energy.

This research tested the hypothesis that this rate structure is unfairly allocating system costs to residential customers. The demand charge was designed to incentivize a flat load profile and provides financial incentive for limiting variability in demand from commercial and industrial customers. As the cost of energy becomes increasingly weather dependent, we questioned the real system value of a flat load that does not respond to dynamic changes in the available supply of electricity. A regression analysis testing the impact of demand charges on utility pricing structure provides evidence of cost shifting onto residential customers. This research further suggested that demand charge rate structures may be limiting the market for new customer-level load shaping technologies. Weak pricing signals that do not reward aligning energy use with available supply will in turn weaken demand for renewable energy technologies like storage and distributed generation. By updating the demand charge rate structure and creating a pricing scheme that aligns utility pricing with costs, new markets for aggregators and renewable energy entrepreneurs could emerge. A review of alternative options for updating the demand charge provides a list of potential pathways forward for regulators, utilities, and renewable energy entrepreneurs as they work to reduce system costs.

1.3.3 Drivers of Environmental Signaling in Electric Utilities

At the heart of the US energy system are almost 3,000 electric distribution utilities providing power to businesses and households (US EIA, 2019). They choose what type of power to purchase on the wholesale market or to generate themselves, maintain the wires and poles of their system, and engage directly with residential, commercial, and industrial customers. These utilities are the gatekeepers of the US electric system. Their willingness to participate in niche-level pilot programs is a key constraint in testing and diffusing innovative smart grid technologies. Some utilities are very proactive and have emerged as outspoken advocates of renewable energy while others have actively resisted efforts to decarbonize their fuel supply (Cardwell, 2017;

Pyper, 2016). State regulators and policy makers have explored various strategies to support utility transitions to renewables, from requiring a percentage of fuel to come through renewables (Renewable Portfolio Standards) to opening up the market to competition so that utilities have to compete for clients (deregulation). Variability in utility positioning remains pervasive, however, and no clear consensus has emerged around how best to support utility decarbonization efforts.

Institutional resource-based theory posits that firm performance can be influenced by characteristics of the firm leader, the firm itself, and inter-firm factors that impact a group of firms (Oliver, 1997). The literature on entrepreneurial orientation further suggests that factors like firm size, market dynamism, and firm age can all impact the entrepreneurial orientation (EO) of a firm, defined as the level of innovation, proactiveness, and risk-taking behavior (Rauch et al., 2009). By measuring the entrepreneurial orientation of 170 electric utilities through a text-based analysis of their Integrated Resource Plans (IRPs) we were able to construct a database that ranked all of the utilities in the data set according to the level of entrepreneurial orientation. Our results revealed a significant correlation between firm EO and two firm performance metrics: percentage of power from renewables in the fuel mix and renewability orientation as expressed in the IRP planning documents. In addition, we were able to measure the effects of factors like state rurality, deregulation, gender of the manager, and renewable portfolio standards. These findings will enable regulators and policy makers to find new ways to support innovation among distribution utilities. By creating conditions where utilities are more likely to lean into the transition, niche protective spaces and renewable generation can proliferate.

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Chapter 2

Defeat the Peak: Behavioral Insights for Electricity Demand Response Program Design[1]

Abstract

Electric utilities and regulators primarily rely on rate design strategies and economic incentives to achieve customer load malleability at the residential level. However, demand-side management strategies are broadening to incorporate new motivational cues based on pro-social impulses to reduce negative environmental impact and contribute meaningfully to local communities. This evolving relationship between residential customers and utilities is explored to better understand the potential for load malleability achieved through non-economic incentive structures and rate design. Following a review of interdisciplinary perspectives on pro-social behavior and utility demand-side management strategies, we analyze the impact of a pro-social demand response program on the energy use of over 16,000 households served by a municipally owned electric utility in Burlington, Vermont, USA. Results indicate that the program achieved a 13.5% decrease in energy use during the peak annual event in August 2018 with a return on investment of 11 to 1 for the distribution utility. This study builds on the work of other researchers studying individual energy behavior change and supports the argument that pro-social incentives can improve the effectiveness of demand response programs.

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[1]

Keywords:

Energy utility industry; Energy system transition; Demand response; Behavioral economics; Demand-side management; Pro-Social Incentives

2.1 Introduction

The structure, timing, and ownership of electricity supply has changed fundamentally in recent years. As solar and wind installations become increasingly common, the decentralized nature of new electricity supply presents new challenges to grid operators. Where energy used to flow mainly from large, centralized generation facilities to consumers, power lines are now bi-directional, channelling energy produced at customer sites back onto the grid. Further, utility scale renewable energy installations are growing in number, creating a power supply that is weather dependent and thus more difficult to predict. Although growth in United States renewable energy capacity has recently slowed, renewable energy generation has doubled since 2008 and represented 17.6% of total electricity generation in (US Energy Information Administration, 2019). This capacity is on par with global renewable penetration, which represented more than 26% of global electricity generation in 2018 with 70% of new installed capacity in 2017 coming from renewable sources (REN21, 2018, 2019).

Base load from coal, oil, and natural gas fired plants have been historically reliable, allowing utilities to plan ahead and ensure that even the highest levels of demand can consistently be met. As load reliability erodes as a result of the shift from fossil fuel-based energy sources to renewable generation, electric utilities are feeling new pressures to actively manage and control energy demand, especially given the growth in public and private renewable energy targets and greenhouse gas commitments (Federal Energy

Regulatory Committee, 2018; World Economic Forum, 2017). Thirty states in the US have passed Renewable Portfolio Standards (RPS) mandating renewable electricity load shares, while an additional eight states have passed voluntary renewable energy standards (National Conference of State Legislatures, 2019). While most state targets require between 10 and 45 percent of utility load to come from renewable energy, seven states have targets of 50 percent or more (National Conference of State Legislatures, 2019). As renewable energy production increases both globally and nationally, utilities are seeking ways to balance their supply and demand.

This changing energy landscape is leading to many new interventions to help match fluctuating demand and supply. Direct control and interruptible/curtailable demand response programs (Albadi and El-Saadany, 2008), new battery storage technology and load control devices that stagger power flow to large household appliances (Hadjipaschalis et al., 2009; Ruiz et al., 2009), and financial incentives through energy efficiency programs (Albadi and El-Saadany, 2008; Arimura et al., 2012; Gillingham et al., 2009) are all ways that utilities are attempting to better control consumer demands under increasingly weather-dependent characteristics of emerging generation technologies. Utilities are especially motivated to reduce energy demand during costly peak periods, particularly short 'peak events' used by grid regulators to lock-in future prices from wholesale markets. In the United States, the amount of energy used during peak events is what determines capacity costs for utilities and comprises about 25% of a utility's total wholesale costs (Direct Energy, 2019; Linares, 2018).

The primary mechanism for managing both ongoing and peak-based demand has been rate design strategies to send market-based signals to customers. These programs include classical demand response programs such as direct control and interruptible curtailable programs, as well as price-based programs like time of use, critical peak pricing, and real time pricing (Albadi and El-Saadany, 2008). However, in a recent study that analyzed 15 years of demand side management (DSM) programming, demand side management programs were estimated to have only produced on average a 0.9 percent savings in electricity consumption, with an average cost to utilities of 5 cents per kilowatt-hour (kWh) saved when calculated with a 5 percent discount on future savings (Arimura et al., 2012). The reason for this limited uptake has been analyzed extensively, with market and behavioral failures at the root of the limited impact of existing programming efforts (Gillingham et al., 2009; Shogren and Taylor, 2008; Wood et al., 2014).

In contrast to traditional economic incentives, there is mounting evidence that customers respond to non-economic motivations to change energy demand. For example, growing research in behavioral economics has demonstrated significant influence of non-financial, pro-social impulses in consumer decision-making (Ariely, 2008; Gintis, 2000; Kahneman and Egan, 2011; Thaler and Sunstein, 2009). Research in the energy industry has incorporated such findings into programmatic design, exploiting pro-social behavioral impulses to increase program effectiveness (Benartzi et al., 2017; Johnson et al., 2017; van der Werff et al., 2019). For example, OPower created a program where electric bills included local neighborhood energy demand comparisons. By leveraging findings on descriptive social norms, loss language, and neighbor comparison they designed a demand management intervention resulting in a 2 to 4% reduction in overall consumer energy use (Cuddy et al., 2010; Laskey and Kavazovic, 2011).

To explore the potential for utilizing pro-social behavior to manage peak electricity demand, we analyze the Defeat the Peak demand response program developed by the Burlington Electric Department (BED), a municipal electric utility in the city of Burlington, Vermont in the Northeastern USA. The paper begins with an overview of utility cost structures related to customer demand. A discussion of the various approaches to managing energy demand highlights research on pro-social demand response programming. Next, the Defeat the Peak program and statistical tests are described in more detail, including an assessment of return on investment. The results of this analysis are then contextualized within similar studies conducted in the energy industry and the context of the larger energy system transition, suggesting broader implications that pro-social incentives might have for electric load management and the successful incorporation of renewable energy resources into the grid.

2.2 Background

Demand side management is critically important for energy security and managing the complexities of a grid where generation is increasingly weather dependent. While historical approaches have been more focused on the wholesale segment of the industry, increasing attention is being paid to retail electricity rates (Kim and Shcherbakova, 2011; Vandenbergh, 2005). In the energy industry, household energy behavior is divided into two categories: efficiency and curtailment behavior (Abrahamse et al., 2005; Gardner and Stern, 2008). Efficiency behaviors are primarily concerned with influencing one-time purchasing behaviors, such as the decision to weatherize a home or purchase an energy efficient appliance (Asensio and Delmas, 2015; Brown and Vergragt, 2016; Cuddy et al., 2010; Dietz et al., 2009; Orland et al., 2014). Curtailment behavior, on the other hand, is more concerned with enabling short-term, repetitive actions in response to an active need from the utility (Kim and Shcherbakova, 2011). Interdisciplinary research indicates that demand side management can best be achieved through a combination of correcting market failures, providing information and suitable incentives, and motivating collective action (Breukers et al., 2011). An improved understanding of how to more effectively shape energy load at the residential level is critical for driving systemic change in the electric grid.

Utilities are highly incentivized to shape customer load, particularly during the peak hour of the year: the annual peak. The benefits of demand response programming for electric utilities include improved system reliability (Albadi and El-Saadany, 2008; Siano, 2014; Wang et al., 2017), control of price volatility and electricity prices (Albadi and El-Saadany, 2008), and avoided capacity costs (Woolf et al., 2013). Electric utility cost structures are complex, and utility managers employ multiple strategies for reducing costs (Baskette et al., 2006; Busch and Eto, 1996; Herter, 2007). This paper focuses on the annual peak which is used to calculate capacity costs for the following year. The annual peak is one of the thirteen peak hours throughout the year (one each month and one annual hour) where the amount of load required by a distribution utility is used to calculate their costs for the upcoming year via the forward capacity market (Energywatch, 2017; James, 2013). The annual hour is particularly impactful on a utility's bottom line because it represents the utility's demand during the highest demand day of the year, a load level that will determine how much new energy infrastructure needs to be built. Based on what the utility uses during a peak period, they are required to pay a capacity cost to ensure that that same amount of peak energy is available to them the following year, cushioned by a reserve margin. Capacity costs represent an industry average of 25% of a utility's total wholesale market expense, and that number is on the rise (Linares, 2018). The annual peak hour is used to calculate a significant part of the utility's capacity costs, so curtailing energy use during this single hour can dramatically impact a distribution utility's bottom line.

Historically, there have been two main types of demand response programs: price-based and incentive-based programs (Albadi and El-Saadany, 2008). Price-based programs discourage customers from using energy at specific times when overall high energy is predicted. These pricing mechanisms include time of use, critical peak pricing, and extreme day pricing. Incentive-based programs can either be classical, where customers receive participation payments or bill discounts, or market-based where customers are retroactively compensated for participation based on their level of engagement. However, there is a growing body of research on non-economic strategies that could complement existing rate design initiatives and build 'deeper' interactions between utilities and their customers by appealing to pro-social behavior. Growing attention is being paid to these alternative incentive programs, although a need for more quantitative empirical evidence of their efficacy has been expressed (Johnson et al., 2017).

For example, Breukers et al. [31] assessed demand side management strategies using a multidisciplinary approach, comparing perspectives from alternative disciplines in order to develop a sociotechnical approach to demand side management. Their work emphasizes that there is both an individual and social level of change that need to occur, and that these take place on different time scales (Breukers et al., 2011). In a similar vein, we have reviewed literature from multiple disciplines to better understand why pro-social demand response programming might be successful, finding great promise in research from behavioral economics, evolutionary economics, and renewed Darwinian theory.

In the demand side management literature, behavioral economics in general, and nudge theory in particular, is the most dominant theoretical framework used to design pro-social incentive programs, as described in a broad review of energy programming based on behavioral economic theories (Benartzi et al., 2017). Nudge theory differentiates between two different systems in which people process information. System 1 describes fast, automatic responses that are highly susceptible to environmental cues [17]. System 2 is slow and reflective, and takes long-term goals more seriously into consideration. A nudge leverages System 1 thinking and people's tendency to accept defaults passively without dramatically changing economic incentives or forbidding any options (Benartzi et al., 2017). Most discussions in the literature on pro-social demand response programs are rooted in nudge theory, thus implying that System 1 thinking underlies responses to pro-social incentives.

The nudge approach has been applied multiple times in the demand side management literature with some surprising and promising results. A key study by Asensio and Delmas (Asensio and Delmas, 2015) investigated pro-social behavior in the electricity marketplace by telling one group of participants that reducing their energy consumption could reduce pollutants, cancer, and childhood asthma. By framing their energy use or conservation as a decision that would impact the public good, they created a pro-social incentive to curtail energy consumption (Asensio and Delmas, 2015). A second group was given detailed information about the financial burden of their electricity consumption, as well as data on how they compared to the top 10% of energy efficient homes in their housing complex. They observed that participants who received health-based messaging reduced their consumption by 8.2% on average, whereas participants in the financial group showed no significant energy conservation and actually increased their energy consumption by an average of 3.8%. By changing the underlying context of energy conservation to be more about helping others than about making money, this pro-social nudge effectively influenced energy conservation.

Evolutionary economists argue that deviations from rational thinking are not mere anomalies to be corrected, as behavioral economics would suggest, but instead are indications of an extremely complex and individualized decision-making structure influenced by social factors like culture, environment, and institutions (Gowdy, 2008). This body of research also questions the universal applicability of financial incentives, finding evidence of the crowding-out effect of money, which suggests that financial remuneration can actually deter cooperative behavior (Bénabou and Tirole, 2006; Gowdy, 2008; Vohs et al., 2006). Thus, programs studied under the umbrella of nudge theory could also be viewed as an application of evolutionary economic thinking. The theoretical frameworks developed in this heterodox approach are rooted more in evolutionary biology than orthodox economics, and differ from behavioral economics in that they do not agree that human behavior is based on the desire to be rational in the classic economic sense (Gintis, 2000). By applying theories such as evolution by natural selection to understanding the nature of cooperation, a significant body of research on pro-social impulses has been developed.

Cooperative behavior falls under the jurisdiction of altruism, a concept that has received a great deal of attention in the literature and can be understood, from an evolutionary perspective, as a behavior that decreases the fitness of an individual while increasing the fitness of the social group (Simon, 1993). Researchers have found regularities in their research on altruism, noting, for example, that a perceived lack of fairness, described as inequity aversion and often manifested through the presence of free-riders, deters cooperative behavior (Fehr and Schmidt, 2006; Huber et al., 2018). The drivers of altruistic behaviors are still being hotly debated, as models like kin selection theory, reciprocal altruism theory, and competitive altruism suggest evolutionary benefits to possessing altruistic traits (Hardy and Van Vugt, 2006). These models share the assumption that altruism can only exist when the actor receives some type of evolutionary benefit, and that each individual will have a unique constellation of motives (Khalil, 2004; Lehmann and Keller, 2006). The context changes somewhat when long-term, existential threats, such as climate change are under discussion and all actors can benefit from engaging in strategies like energy conservation (Blasch and Ohndorf, 2015).

The core theories of Charles Darwin are also at the center of renewed Darwinian theory. Specifically, renewed Darwinian theory (RD theory) envisions human motivation as a set of four primary drives: the drive to acquire, to bond, to comprehend, and to defend (Lawrence and Nohria, 2002b). Traditional financial incentives target the drive to acquire and accumulate more buying power. The drive to bond is associated with emotions like fairness, loyalty, compassion, empathy, and belonging (Lawrence and Nohria, 2002b). Pro-social incentive programs could be said to appeal to the drive to bond. The drive to comprehend is concerned with curiosity and wonder, and has been observed in a demand side management context as the power of novelty. For example, research on the power of in-home devices to reduce energy demand reveals high usage during an initial period of "intrigue," but that use declines once the information becomes less novel, an effect referred to as the "fallback effect" (Buchanan et al., 2015; Foulds et al., 2017). Lastly, the drive to defend is reactionary and more primal, and relates to impulses around loss aversion (Kahneman and Egan, 2011). Renewed Darwinian theory takes a different perspective to human motivation, suggesting a universal motivational framework that would account for altruistic behavior.

The core tension between prioritizing social versus individual goals sets evolutionary economics and renewed Darwinian theory apart from behavioral economics. These models also differ in the simplicity, or universality, of human motivation. While RD theory and behavioral economics believe that all individuals share the same goal or set of goals, evolutionary economics takes the perspective that complex social structures like institutions and cultural norms all contribute in different ways to an individual's motivational landscape. Thus, while these models do share elements in common, they also differ considerably. Figure 2.1 situates these approaches along axes of social versus individual considerations, and simple/universal versus complex/individualistic. On the horizontal axis, individualistic means that each individual has their own unique constellations of needs and desires. The opposite end of the spectrum is a basic set of one to four universal needs that everyone has in common. On the vertical axis, individual refers to self-serving, whereas social refers to a greater emphasis on being part of the community.

Game design theory is included in the following table as well. Game designers create games that fulfil individual needs but acknowledge that people have different types of needs (Yee, 2006). For example, studies have shown that men are more interested in competition than women (Niederle and Vesterlund, 2011). In each game there is usually a limited number of game design elements designed to satisfy a certain type of individual's personal needs and desires. In this way, players are more concerned with satisfying personal desires for fun and entertainment but each player has a unique constellation of game design elements that appeal most to them.

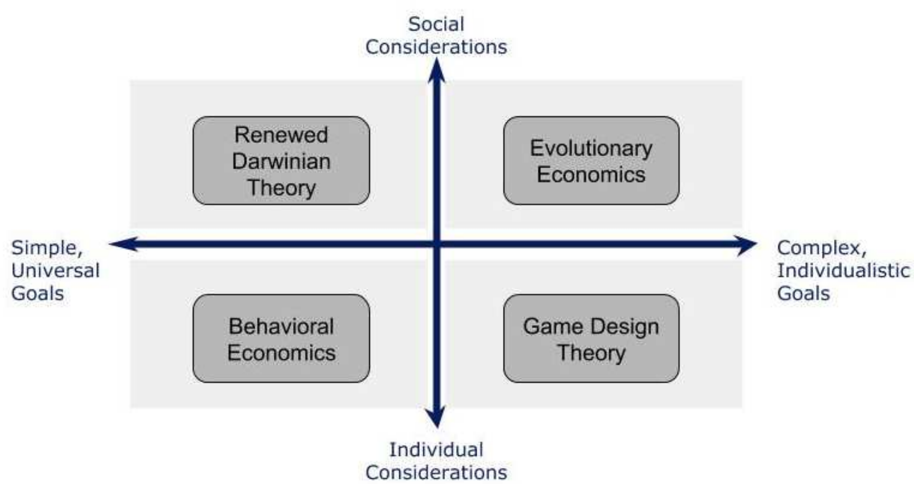

Figure 2.1. Drivers of altruistic behavior.

The following research builds on this framework to investigate a particular application of pro-social incentives for demand side management. By incorporating perspectives from behavioral economics, RD theory, and evolutionary economics, a more diverse array of causal mechanisms can be considered when discussing the results of this experiment. Specifically, this study seeks evidence to support the claim that pro-social incentives can improve consumer participation in demand side management. The next section describes the study and an assessment of its efficacy using a difference-in-differences approach.

2.3 Defeat the Peak study

This study assessed the impact of a pro-social demand response program conducted by the Burlington Electric Department in the summer of 2018. The Burlington Electric Department (BED) is a municipal utility that serves Burlington, Vermont, a city of about 42,000 people in the Northeastern United States. As a public power utility, BED is not-for-profit and owned by local taxpayers. They are only responsible for electricity distribution in the city of Burlington, Vermont and their community ownership structure informs their strategic direction "to serve the energy needs of our customers in a safe, reliable, affordable, and socially responsible manner" (Burlington Electric Department, 2018). BED expressed their commitment to social responsibility by becoming the first city in the United States to be powered by 100% renewable energy in 2015 (Peters, 2015). In recent years they have continued to prioritize social responsibility by investing in comprehensive efficiency programs (Seyler, 2017), accelerator programs to assist renewable energy entrepreneurs (Nottermann, 2019), and leadership in a net-zero greenhouse gas campaign among US mayors (Thurston, 2018).

In line with their mission, BED designed an innovative demand response program called "Defeat the Peak". The program included two separate initiatives: one targeting large commercial accounts and a second exclusively targeting residential customers. The purpose of the residential program was to signal their customers to make a short-term, active choice to curtail their energy consumption in their homes during time periods that might represent the regional annual peak. If the utility could successfully predict the day when the annual peak occurred, a decision that is made by the regional transmission utility retroactively after summer ends, then they could save significantly on their capacity costs. Therefore, during the summer of 2018 the Burlington Electric Department identified six peak events through their Defeat the Peak program and asked consumers to curtail energy use during specific time periods. Only one of those energy curtailment efforts, which occurred on the annual peak on August 29th, actually had the potential to create significant savings for the utility.

Distribution utility cost structures depend heavily upon how much energy they use during the annual peak: the one hour of the year that determines ongoing capacity costs from the regional transmission utility. The annual peak represents the hour with the highest overall level of energy consumption, regionally, in a year. Burlington is part of New England Independent System Operators (ISO-NE), a regional transmission organization that charges for electricity based on distribution utility load during the peak hour of the year across all of their member states, including Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, and most of Maine. Therefore, while ISO-NE's peak hour may not represent a particularly hot day in Vermont, if there is heat wave in Boston and Connecticut the regional peak might still occur. This makes it difficult for the utility to predict when the annual peak hour will be and to convince consumers that a peak event is forthcoming if the weather in their towns isn't uncharacteristically hot.

Participants in Defeat the Peak included all 16,149 grid-connected households without solar or battery installations in Burlington, Vermont. Data was collected from advanced metering infrastructure in 15-minute intervals on days when anticipated peak events occurred, as well as on non-peak control days. Energy consumption levels for the time periods studied were averaged to get a single point estimate for each household. The average energy consumption was also calculated for the time period of identical length immediately preceding the treatment period. Our research analyzed how the average energy consumption (the dependent variable) changed as a result of program activation (the independent variable).

BED hired GameTheory, Co., a company specializing in applied games, to assist in the development of the demand response program. The program was designed to inspire the community to work together to achieve the larger goal of helping the most vulnerable populations in the city through donations to local charities. Every time that the utility anticipated a spike in energy consumption that could represent the annual maximum load, they signaled to customers a Defeat the Peak demand response event. The peak events, summarized in Table 2.1, lasted between two and four hours and coincided with the hours that residents were typically returning from typical nine to five workdays.

Unlike typical financially motivated programs, the incentive to reduce electricity consumption during an anticipated peak event was a $1,000 donation from the municipally-owned utility to a local charity. A notice went out to customers the day before the event with information about the hours that they needed to limit their energy use to benefit a selected charity. The program was designed to elicit feelings of inclusion, collaboration, and altruism. Six peak events were analyzed for all households during the summer of 2018 using a difference-in-difference approach, comparing experimental days with program messaging against similar control days without messaging.

Table 2.1. Defeat the Peak event schedule.

Day of Week	Date	Treatment Time	Temperature (°F)
Monday	07/02/2018	4-7 pm	88.5
Tuesday	07/03/2018	4-7 pm	83.0
Monday	08/06/2018	4-6 pm	85.5
Tuesday	08/07/2018	3-6 pm	78.0
Tuesday	08/28/2018	3-7 pm	83.0
Wednesday	08/29/2018	3-6 pm	83.5

Marketing and awareness building for this program was conducted exclusively via free channels. The program was announced on BED's Twitter feed, press releases, Front Porch Forum[2], Facebook, and BED website. Residents were also invited to sign up for e-mail notifications of Defeat the Peak events, the primary means of outreach. There were six notification emails sent out over the course of the program and two emails informing participants of the program results. The percentage of emails that customers opened (open rate), as well as the percentage of emails where recipients actively clicked on the link within the email (click rate), were higher than the industry standard, with an average of 57.25% and 21.13%, respectively, across the six events. According to Hubspot, utilities are part of the business and industrial companies sector with an average open rate of 41% (Brudner, 2018). Mailchimp, another industry leader in marketing strategy, scanned hundreds of millions of emails sent through their popular email marketing service and concluded that the average open rate for business and finance companies was 20.47% and the average click rate was 2.59%. However, Figure 2.2 does

[2] Front Porch Forum (frontporchforum.com) is a free online community-building platform where residents from towns can communicate with one another through a shared daily newsletter.

point to variability and possible deterioration of the program over the course of the summer.

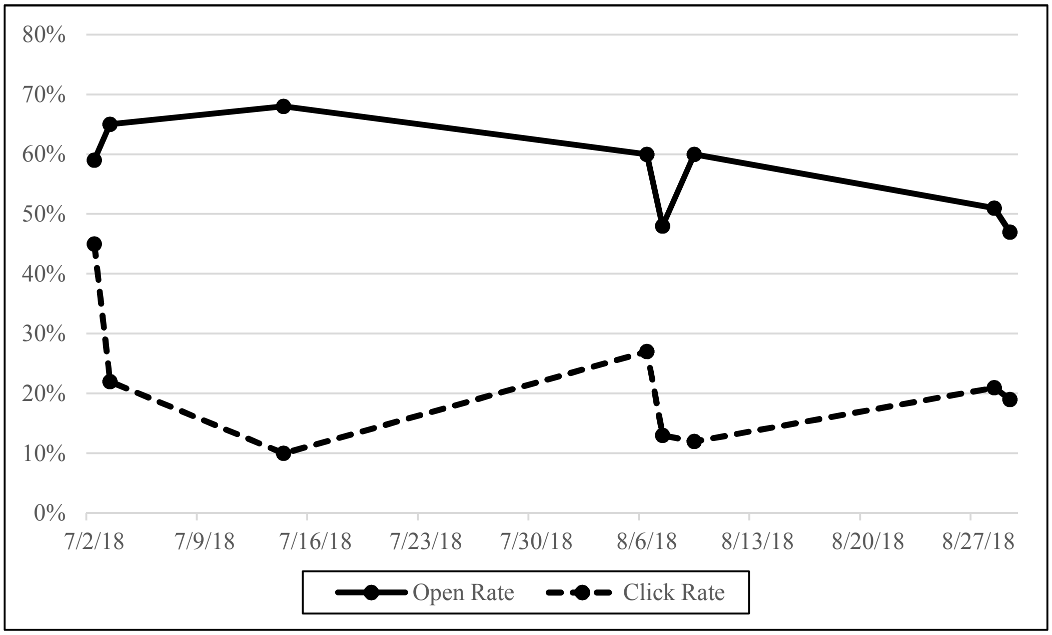

Figure 2.2. Above average open and click rates deteriorated over time.

2.4 Data analysis

We conducted an analysis of variance with a linear model in a two-way repeated measure in order to compare energy consumption before and during the treatment period on a Defeat the Peak Day and with a control day. There are thus four different groups that were measured for each Defeat the Peak (DTP) event. The treatment period was defined by the utility, and there were six different events over the course of the summer.

A difference-in-differences (DID) model allows researchers to measure the impact of a treatment without the time and expense of a formal study with a randomized control group. In a DID model, researchers compare the average change over time during both a treatment day and a control day. By comparing the slopes of the observed changes it is possible to measure the impact of a treatment.

A key concern with difference-in-differences models is the question of whether or not the observed difference in means is due entirely to the policy change (Wooldridge, 2003). To try and isolate the impact of the DTP program, control variables considered for this experiment included temperature, precipitation, whether or not the University of Vermont (UVM) was in session, and if the day in question was a weekday or a weekend. All of the days selected for measurement were weekdays, including both the days when the Defeat the Peak event occurred and those selected for controls, and had similar levels of temperature and precipitation. Since the energy use in Burlington increases by over 10% when UVM is in session, we also made sure that trials were only conducted between days where the UVM student population was either present or absent for both days.

In order to measure the relative impact of the program on Burlington's electricity demand, we needed to create a baseline to show how average energy use changes when people return home from work and there is no demand response program activated. This data represented our counterfactual. The value of a difference-in-differences model hinges on the compatibility of the treatment group to the control group, so this was a critical step (Oosterbeek et al., 2010). We took multiple approaches to constructing counterfactuals for each experiment. We first controlled for day of the week and precipitation to ensure that any day we chose would be comparable to the day where the program was activated. We then selected the day from the same week that had either the most similar temperature or fell on the same weekday. This strategy provided multiple comparison groups in order to allow for more checks on the hypothesis (Meyer, 1995).

Selection of control days was a critical component of the research. Based on conversations with BED we chose to prioritize proximity to the treatment day, as Burlington customers tend to increase their air conditioner usage as the summer progresses (and they become increasingly impatient with the heat). Day of the week was also an important component. Therefore most of our studies compared the treatment day with the day exactly a week before and in four of the tests precipitation levels for the control days was extremely similar or identical to precipitation for treatment days. We added two additional "random hot day" tests (4 and 6) to make sure that the difference in behavior was not attributable to behavior that occurs on hot days. Since peak energy events tend to occur on the hottest days of the summer, there was often a difference in baseline energy use between the Defeat the Peak day and the control day. To account for the potential scenario where energy behavior is simply different on hotter days, random hot weekdays that were not Defeat the Peak event days were used as controls in subsequent trials. Other considerations that proved challenging included accounting for vacation days. Two Defeat the Peak events occurred during the week of the July 4 holiday, so some energy use behaviors may have been affected by vacation-based scheduling abnormalities.

The difference-in-differences model allowed us to compare how energy use changed during days when Defeat the Peak treatments were active to days when there was no Defeat the Peak event. We compared energy usage in time period 1 (the hours before the Defeat the Peak event) to time period 2 (the hours during the Defeat the Peak event) for both the treatment day and a control day. While there was no Defeat the Peak event during the control day, we compared the same two time periods. Household electricity consumption (Y) was therefore analyzed with a repeated measures model using the following ANOVA linear mixed model:

$$Y_{ijk} = \mu + \alpha_i + \gamma_k + \alpha\gamma_{ik} + \varepsilon_{ijk} \quad (1)$$

where i = 1, 2 (experiment vs. control day), j = 1 to 16,149 (households), and k = 1, 2 (time period before vs. during DTP event). The μ is the overall usage mean, averaged over all households for both days and time periods, α is the effect of the day, γ is the effect of the time period, α*γ is the interaction effect, and ε is the random error. We were most interested in the interaction effect because it tested whether the difference between time periods one and two was the same on both days.

2.5 Results and Discussion

2.5.1 Paired T-Tests

Six tests were performed to understand if Burlington city residents increased their energy consumption to a lesser degree on days when a Defeat the Peak event was called as compared to the control days (see Table 2.2). The control days were selected based on their proximity to the event day, the day of the week, the level of precipitation, the temperature, and whether or not the University of Vermont was in session. Energy loads can differ significantly across days of the week, particularly when comparing weekdays to weekends (Parker, 2003). Further, energy consumption patterns change over the course of the summer as well, with consumers more likely to use air conditioners at the end of the summer (Lamont, 2018). As a result of these trends, we felt that it was more appropriate to select a single control day that shared the most characteristics possible with the treatment day instead of comparing to an average baseline.

In this analysis the null hypothesis, that the Defeat the Peak program would not significantly effect energy consumption during peak events, was rejected five out of six times. The percentage increase in energy consumption when Burlington city residents returned home was significantly lower in 83.33% of the testing done. This evidence supports the conclusion that the Defeat the Peak program did significantly change energy behavior. While the average temperatures on the control and experimental days were not always similar, energy usage between the two time periods increased more on the control days (as a percentage increase) than on the experimental days.

Table 2.2. Six tests analyzing impact of the Defeat the Peak demand response program.

Test	Control or Treatment	Day of Week	Date 2018	Precipi-tation	Temp (°F)	Treat-ment time	Average Usage Before (kWh)	Average Usage During (kWh)	Slope of change	Percent change	Significance
1	Treatment	Monday	07/02	.04	88.5°	4-7 pm	3.00	3.29	0.284	9.67%	$p < 0.0001$
	Control	Monday	06/25	.03	63.0°		1.33	1.55	0.220	16.50%	
2	Treatment	Tuesday	07/03	0	83.0°	4-7 pm	2.82	3.14	0.314	11.13%	$p < 0.0001$
	Control	Tuesday	06/26	0	63.0°		1.31	1.56	0.250	19.08%	
3	Treatment	Monday	08/06	0	85.5°	4-6 pm	1.80	1.95	0.155	8.61%	$p = 0.41$
	Control	Monday	07/30	0	72.0°		1.28	1.45	0.163	12.73%	
4	Treatment	Tuesday	08/07	0.69	78.0°	3-6 pm	2.28	2.38	0.099	4.34%	$p < 0.0001$
	Control	Wednesday	08/22	0	72.5°		2.06	2.28	0.223	10.83%	
5	Treatment	Wednesday	08/29	.02	83.5°	3-6 pm	2.53	2.84	0.303	11.98%	$p < 0.0001$
	Control	Wednesday	09/05	0	78.5°		2.10	2.64	0.535	25.48%	
6	Treatment	Tuesday	08/07	.69	78.0°	3-6 pm	2.28	2.38	0.099	4.34%	$p < 0.0001$
	Control	Tuesday	07/17	.01	81.0°		2.30	2.51	0.206	8.96%	

Figure 2.3 illustrates the pairing of the July 17th control day with the August 7th treatment day. The flatter slopes that characterize the change in average energy consumption before and during the peak treatment is indicative of the type of change in energy behavior that is observed in successful demand response programming. There are three ways in which users typically respond to peak events: curtail usage during the peak, shifting use of major appliances like the washing machine and dishwasher to other times, or pre-heating or pre-cooling a room before the event (Wu et al., 2012). Therefore, users may use more energy before an event in order to pre-cool a room, an action that would make the average level of energy consumption used before the event relatively higher than it would have been otherwise. The increase in consumption during the event time period would not be as incrementally significant were these actions taken, thus resulting in a flatter demand curve on treatment days than on control days.

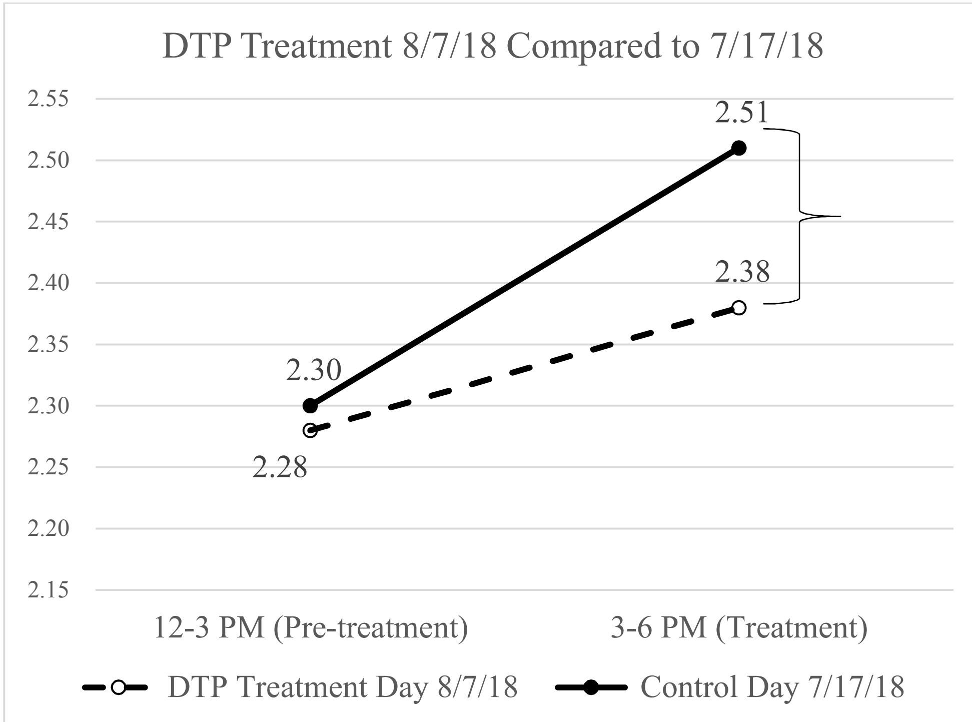

Figure 2.3. Sample result from Defeat the Peak analysis.

2.5.2 Payback Analysis

While all six treatments were evaluated, only one of the Defeat the Peak event days (Test 5 in Table 2.2) actually resulted in the utility saving money. This is because the annual ISO-NE peak electricity hour for 2018 occurred on August 29. The annual cost structure for all utilities in ISO-NE, including Burlington Electric, are heavily dependent upon their energy consumption during this single hour of the year. In order to compute the actual savings derived from the implementation of the Defeat the Peak program in 2018, we therefore applied the same methodology to the actual peak hour on August 29th and selected the control day that was closest in proximity, precipitation, and weather conditions. There was no payback analysis for any day other than the day in which the actual peak occurred

(August 29). The other days did not have any impact on utility wholesale costs because pricing is determined by that one hour of annual peak.

The first step in calculating the financial benefit of the program was to identify how many kWh were avoided as a result of the Defeat the Peak treatment. The strategy for calculating this is based upon the belief that in a counterfactual scenario, where there was no Defeat the Peak program, energy use would have increased to the same degree that it did on the control day of September 5, 2018 of 25.48%. September 5th was selected as the closest in temperature to the experimental day among all days in the weeks following and preceding the Defeat the Peak event. If energy consumption on August 29th had increased by the same percentage as it did on September 5th, then the average energy use for the three-hour period when the program was active would have been 51,270 kWh, which is 5,521 more kWh than was actually observed. Thus, the kWh avoided during the peak hour on August 29th can be calculated as one third of the average energy consumed during the three-hour peak period, or 1,840 kWh.

To calculate the avoided cost we needed to ascertain the value of the avoided 1,840 kWh during the peak. The 2018 Forward Capacity Market set the cost of every kWh used during the peak period as $7.03 per kWh which is paid monthly over the following year. In addition to the charge per kWh, Vermont distribution utilities must pay an additional 20% over their actual usage to fulfill their reserve ratio requirements every month for the following year. Anticipated line losses are also assessed in a similar way, by adding a 3% buffer to the monthly cost. In order to determine the annual savings, we first multiplied the avoided kWh (1,840) by $7.03. Next, in order to account for reserve ratios and line losses, we multiplied that number by 23% (20% for the reserve ratio requirement plus the 3% line loss buffer). This provided the monthly savings which we then annualized in order to find the ultimate annual savings of $191,918, which in 2018 would have represented 1.1% of their purchased power expense (KPMG LLP, 2019).

BED estimated the direct cost of the program implementation as $6,000 ($1,000 donations to six local charities over the course of the program) in addition to indirect costs such as employee time for marketing, design, and implementation. In order to estimate the indirect costs of employee time, we found that the average salary of a marketing coordinator in the electric industry is $54,743 [61]. However, the real cost of an employee includes benefits, recruiting expenses, employment taxes, space, and equipment which results in an employee cost estimated between 1.2 and 2.7 times the actual salary, depending on the level of equipment and amount of space required [62]. Thus, if we conservatively assume that the actual cost of a Marketing Coordinator is 2.7 times their salary, then their hourly cost would be about $77. If we assume that the Marketing Coordinator spent 40 hours designing the graphics, communication strategy, and establishing partnerships with local charities, plus two hours implementing each event, then the total indirect costs associated with the Defeat the Peak program would be about $10,000. We can then assume that total direct and indirect costs are, roughly, $16,000. By dividing the net benefit ($191,918 less $16,000) by the total expense, we calculated an ROI of 11 to 1; for every one dollar invested in the program, the utility generated eleven dollars in savings.

In order to contextualize these savings within the academic literature, Table 2.3 reconstructs an analysis completed by Benartzi et al. [74] with the addition of results from this study. This table compares different energy curtailment programs based on both nudge theory and more traditional financial incentives. A key difference between these programs is in the type of program being measured. Defeat the Peak was a Demand

Response program designed to achieve a brief 1-hour energy curtailment. OPower and Asensio & Delmas created programs with the more long term goal of energy efficiency, a type of program that is more concerned with long term purchasing patterns (i.e. more energy efficient refrigerators.) The results recorded for the DTP program measured a curtailment-related charge of just a few hours in contrast to a long term change in average energy consumed.

Table 2.3. Comparison of program effectiveness contextualizing analysis from Defeat the Peak 2018. (Adapted from Benartzi et al. [74])

Article	Inter-vention	Treatment	Impact	Cost	Relative Effectiveness
Allcott [73]	Nudge	Residential users received reports comparing their energy usage to their neighbors as well as energy conservation tips	2% average reduction in energy usage	$1 per report, distributed 1-4 times/yr	27.3 kWh saved per $1 spent
Asensio & Delmas [27]	Nudge	Consumers received health & environmental messaging and appliance-level feedback on energy use	8.192% decrease in energy use	$3.019 per household	.05 kWh saved per $1 spent
Ito (Ito, 2015)	Financial Incentive	California residents received bill discounts if they reduced energy consumption by 20% compared to previous summer	4.2% reduction inland; neglig-ible in coastal areas	$5.09 per customer	3.41 kWh saved per $1 spent
Arimura et al. [9]	Financial Incentive & Education	Incentives and education for peak management and energy efficiency	0.9% decrease during pro-gram; 1.8% when including future periods	$10.83 per customer (on average)	14 kWh saved per $1 spent
Pratt & Erickson	Pro-Social	Utilities donated to local charities when residential users responded in aggregate to demand response events	13.5 % decrease in energy use during peak period	$.031 per household	0.12 kWh saved during annual peak hour per $1 spent

2.5.3 Discussion

Campaigns to influence individual energy behavior are often viewed with skepticism, as critics question the possibility of reaching environmental goals at a reasonable cost and level of intrusiveness (Barkenbus, 2010; Vandenbergh, 2005). As a result, best practices from existing research are often overlooked during new program design (Barkenbus, 2010). The Defeat the Peak program is an example of an individual behavior change program that leveraged some important best practices around designing the motivational backdrop, but missed other opportunities such as suggesting specific energy curtailment strategies.

The messaging of the Defeat the Peak programming was based around the straightforward recommendation that users should use less energy during a peak event (BED, 2018). While the results of this paper indicate that consumers were able to meaningfully respond to this unspecific request, prior research has shown that consumers are frequently unaware of the most effective ways to reduce their overall energy use, and tend to over-emphasize the importance of curtailment while under-emphasizing efficiency improvements (Attari et al., 2010; Gardner and Stern, 2008). Attari et al [68] observed that consumers significantly underestimated the energy embedded in an activity or device when the actual use and savings were high. This finding indicates that participants may not have realized the impact that their electric dryers or desktop computers may have had on their overall energy consumption during the peak. Had the Defeat the Peak program incorporated this research finding into their program design, they could have added more specific recommendations for responding to the peak such as pre-cooling rooms, shifting the use of large appliances, and sacrificing comfort by limiting lighting or hot showers (Wu et al., 2012).

There are additional ways in which this program could be improved in future implementations. Financial payback could likely have been improved by engaging more with local businesses, both as a means to communicate with their customers and also to get their cooperation in curtailing consumption. In addition, the peak event notifications could be better publicized and marketing spend could be used to actively push these notifications out to customers. Celebrating successes more openly and obviously would further build community and momentum for this program.

While it could be argued that the residents of Burlington, Vermont are highly concerned about the environment and thus might be more capable of effectively responding to broad signaling from the utility, the results of Attari et al.'s [68] study shed doubt upon that possibility. Their analysis yielded the unexpected finding that users who engaged in more energy conserving behavior were less accurate in their comparisons of various energy behaviors and devices (Attari et al., 2010). Therefore, the environmental culture of Burlington, Vermont may actually have resulted in a decreased ability to effectively respond to the utilities' signaling. By better leveraging the existing studies on behavioral interventions, programming such as Defeat the Peak can continue to improve and provide further evidence of the importance of behavioral approaches to climate change.

Towards this end, these results answer a call from multiple disciplines to provide more empirical, large-scale studies of pro-social incentives effectively motivating energy behavior change (Benartzi et al., 2017; Johnson et al., 2017). Despite the lack of clear instructions to consumers on how to curtail energy consumption during the peak event, there was a significantly flatter demand curve on five of the six days in which peak events were called (see Table 2.2). While the utility's financial benefits were tied to just one of these events, the day of the actual annual peak, the research value of the experiment goes much further. This analysis demonstrated that on five separate occasions, an entire city was willing to come together and engage in cooperative behavior to secure a donation to a local charity. This research provides further evidence that pro-social incentives can be effective in demand side management programs.

The question that remains outstanding is why it worked. Behavioral economics, evolutionary economics, and renewed Darwinian theory all offer different rationales and theoretical frameworks within which these results might be framed and understood. While there are multiple examples of nudge theory at work in the demand side management literature, there are fewer attempts to contextualize pro-social DSM programs within the disciplines of evolutionary economics and renewed Darwinian theory.

Behavioral economists might describe this program as an example of a nudge, due to the absence of strong economic incentives and the subtle repositioning of the energy curtailment request as relating to the public good rather than to financial gain. This study would support the conclusions of Imas et al. [69] that pro-social incentives can improve performance and effort provision as long as the stakes are low (Imas, 2014). Further, the programmatic design is similar to the health-based energy literacy campaign studied by Asensio et al. [27], which was included in Benartzi et al.'s [19] summary of nudge-based campaigns. Behavioral economists would frame the decision to conserve energy on a peak day as a decision falling under the purview of System 1, the faster system that is more likely to be swayed by subtle environmental cues in its attempt to make rational choices. The utility's messaging thus changed the context of the individual's decision-making and made it easier for them to make a cooperative, pro-social choice about energy conservation.

Evolutionary economists might view this research as an important step towards applying insights on altruism and cooperation to the context of climate change (Blasch and Ohndorf, 2015; Gowdy, 2008). Further, this research framework would be interested in the anonymity of the program, as program participation was completely anonymous. Anonymous giving is considered to be an interesting area of altruism research because it is both the most rare form of donation but also the most respected (Bénabou and Tirole, 2006). While anonymity may deny participants the chance to gain recognition for their good deed, they may still have experienced a 'warm glow' of giving; a private utility of psychological benefits resulting from altruistic behavior (Andreoni, 1990; Blasch and Ohndorf, 2015). Follow-up research could explore this theory through interviews with participants structured to deepen our understanding of how organizational identification, altruism, and other motives beyond economic gain impacted participants' decision to participate (Simon, 1993). The evolutionary literature would treat this research as an extension of the existing literature on altruism, cooperation, and the interaction of culture and institutions on human decision-making.

Renewed Darwinian researchers might interpret the findings of this study as evidence of an effective strategy targeting the drive to bond. This drive was developed by the founders of RD theory as an attempt to integrate research on belongingness into their model of human behavior (Pirson and Lawrence, 2010). Therefore, this study would be situated amidst studies on the belongingness hypothesis, where there is an extensive literature documenting the existence of a primary drive to create and maintain social bonds, as summarized in the review by Baumeister and Leary (Baumeister and Leary, 1995).

2.6 Limitations, Outlook, and Future Work

As utilities are increasingly motivated to make residential loads more malleable, researchers from multiple disciplines are investigating ways to improve the effectiveness of existing rate design strategies for demand response programming. This analysis adds to the growing body of research on energy behavior and demand response programming, providing empirical evidence that pro-social incentives can be effective while also investigating three perspectives as to why that might be the case.

The utility achieved savings at a fraction of the expense of other demand response programs (see Table 2.3) supporting the finding that programs that use pro-social cues are typically inexpensive for utilities to implement relative to price subsidies and can have impacts comparable to large changes in price (Allcott, 2011). Similar to other program evaluation studies (Allcott, 2011; Thaler and Benartzi, 2004), there are limitations as to how broadly these results can be interpreted. While the pro-social incentives in this program could be interpreted through the lens of behavioral economics, evolutionary economics, and renewed Darwinian theory, a lack of participant interviews or surveys makes it difficult to test more granular hypotheses about the specific reasons why this program was effective.

A deeper conclusion that this research would support is that demand response programs do not necessarily need to be “shallow,” as recommended by the World Economic Forum (World Economic Forum, 2017). Customers may be willing to actively engage with demand response programs with a pro-social benefit to a degree that could significantly improve utility cost structures and corollary environmental benefits. While there are limits to the degree of change that households may be willing to voluntarily consider (Imas, 2014), research suggests that households have the potential to become active participants in efforts to curtail emissions (Dubois et al., 2019).

A more far-reaching hypothesis that emerges from this work is that people are compassionate and cooperative. Individuals have the potential to become active, involved stakeholders in the energy system transition and repudiate the social and environmental injustices embedded in today’s methods of extracting and distributing energy. People may do this because they genuinely want to help their communities and be a part of an effort greater than themselves. As Victor Frankl (Frankl, 1985), the founder of a sub-discipline of psychology known as logotherapy, describes:

What man actually needs is not a tensionless state but rather the striving and struggling for some goal worthy of him. What he needs is not the discharge of tension at any cost, but the call of a potential meaning waiting to be fulfilled by him.

The stakes of this transition are high and require the involvement of passionate, engaged individuals who are inspired by a new renewable and more socially just future. As Frankl suggests, engagement in these efforts could have positive manifestations within the individual while also meeting the goals of electric utilities, state renewable energy targets, and larger efforts to reduce greenhouse gas emissions.

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Chapter 3

Re-Aligning Electricity Demand Charges to Meet Economic, Social, and Environmental Goals

Abstract

For over a century the demand charge has been a primary source of revenue for utilities to recover their total cost-of-service including fixed, embedded, and overhead costs. However, new societal goals for more renewable energy sources, efficiency and conservation, and electrification of transportation may require a different type of revenue recovery mechanism for utilities that both incentivizes the energy transition and fairly allocate costs across customer classes. Under the current system, most small commercial and residential customers do not receive a strong direct price signal to invest in storage, load shifting, or renewables. Larger commercial and industrial customers exercise some measure of control over their loads to reduce demand charges, but with only modest benefit or value to the system as a whole. The system costs are then redistributed to all customer classes, potentially in way that falls disproportionately on small commercial and residential customers. To investigate, we conduct a regression analysis with data from 447 electric utilities. Results suggest that demand charges predict a significant degree of variability in residential pricing.

Regulation is complex, even more so in an era of distributed energy resources and increasingly competitive markets. Rates are often based on *historical costs, but have their most profound impact on future behaviors and costs. (Rábago and Valova, 2018).*

3.1 Introduction

Rábago and Valova's perspective on the danger of outdated policies highlights the risks of failing to refresh or embed dynamism in policies to make them adaptable to changes in circumstance. Electric utilities face the unparalleled challenge of matching the time of production (generation) to retail delivery 100% of the time to all of their customers despite significant fluctuations in demand that occur daily, monthly, and annually. Commercial and industrial customers in particular can have extremely variable/intermittent peak loads, resulting in demand profiles that require a high level of electricity to be made available immediately but only for a short period of time. In order to make this possible, utilities need to invest in sufficient grid infrastructure and power supply to accommodate these localized and short duration high demand periods (and often for low load factor customers).[3] Since these periods can be short and unpredictable, the fixed costs of extra capacity that is often idle is not offset by marginal revenues from occasional increases in electricity sales. This leaves utilities and regulators in a difficult position, as raising rates for everyone would result in high load factor (less "peaky") customers subsidizing low load factor (relatively "peaky") customers.

Demand charges are already recognized as the primary mechanism by which utilities in the United States recover capacity-related costs from commercial and industrial customers. It is also the major source of revenue for recovery of embedded costs like historic commitments, long lived investments, and other costs of the system

[3] The "load factor" pertains to the relationship between peak and average load. Low load factor customers have a high proportion of load, or average load, relative to their peak demand.

necessary to recover the full revenue requirement (the total cost-of-service). In contrast to regular consumption charges billed at a fixed per unit price ($/kWh), demand charges are based on the maximum amount of power (kW) consumed in any given time interval (e.g., 15 minutes) multiplied by a separate fixed price ($/kW).[4] While consumption charges capture the actual minute-to-minute use of energy, demand charges try to recuperate some of the additional infrastructure costs related to the peak capacity requirements of the system, thus keeping the hourly consumption charges down for everyone. Historically demand charges have only been applied to industrial and larger commercial consumers,[5] providing an incentive to flatten their demand by spreading it out more evenly over the day. These additional charges to commercial and industrial customers typically represent between 30 and 70 percent of their total electric bill (McLaren et al., 2017). All else being equal, this strong incentive to smooth out loads should reduce system costs, reducing the amount of infrastructure a utility needs to build.

When the vast majority of energy generation came from predictable fossil fuels, hydropower, and nuclear sources, it was easy to manipulate and predict energy supply costs and set demand charges. However, this strategy is no longer compatible with new system technologies, generation profiles, and policy goals. Today's energy supply is becoming less dispatchable and less predictable as weather, rather than operating decisions from system control, establish when plants generate electricity. Weather-dependent generation cannot be easily turned up or down to match customer demand making it difficult for utilities to accommodate customers with low load factors. The

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4 Customer charges are typically the third component, but represent a comparatively small share of the revenue requirement.

5 Occasionally utilities have a separate demand charge for large residential loads. Three utilities in Vermont, for example, have residential demand charges.

challenge today is to incentivize customers to flex their loads in response to the availability of power on the grid.

There are three primary customer classes in the United States power system: residential, commercial, and industrial customers. Commercial customers accounts for more than a third of electricity consumption in the United States and includes government facilities and other service-providing businesses that are both public and private (United States Environmental Protection Agency, 2020). Industrial customers, on the other hand, use electricity for processing, assembling, or producing goods for industries like mining, manufacturing, and agriculture and tend to have much higher and steadier levels of demand (United States Environmental Protection Agency, 2020) (EIA, 2017).

The literature on demand charges has largely focused on cost avoidance strategies for commercial and industrial (C&I) customers, noting that there is "no clear indication" that demand charge rate structures will be changing in the near future (Zhang and Augenbroe, 2018). Yet there are potential pathways that regulators are considering to sharpen pricing signals to all customer classes in order to curtail system costs. This research fills a gap in the literature by investigating the historic, current, and future economic efficiency of the current demand charge structure that predominates the US electric grid. A particular focus on the impact of demand charges on different types of customers is assessed using a regression analysis. Utilities and regulators seek to ensure that customers with a high load factor are not unfairly burdened by low load factor customers. Put another way, they seek a fair apportionment of what (Bonbright et al., 1961) referred to as the residual or "burden" (overhead and embedded costs above direct incremental or marginal costs). However, grid costs are driven increasingly by wholesale level costs while industrial customers receive pricing signals that are increasingly unaligned with wholesale costs and they responding accordingly. Instead of investing in technologies to match weather-dependent energy supply, these customers are changing their demand in such a way that lowers their prices but doesn't change utility expenses. The utility still has to collect money from somewhere, so we hypothesize that this situation may result in higher residential rates. In other words, current demand charges may be shifting an unfair cost burden on to residential customers.

To investigate this potential cost shifting, we compiled the commercial, industrial, and residential rates of 447 electric utilities to explore the relationship between the percentage of revenue that a utility receives from demand charges and the energy costs borne by residential versus C&I customers. If demand charges function as they are intended, high demand charges should represent a stronger price signal and drive down avoidable components of capacity-related system costs, lowering costs for both affected customers and the system as a whole. As the price signals impact load-related demands that typically center on customer loads instead of system loads, demand-related drivers of apportionment (i.e. the assignment of overhead costs that are not avoidable) are re-spread to other customer classes. The question investigated here is whether or not the appropriate balance has been achieved. In other words, are demand charges driving down capacity-related costs enough to offset the cost burden that is being spread across other customer classes? A poor or inefficient price signal misaligned with system costs would unfairly share the high capacity burden among all customers. These higher costs may be borne at a higher rate by non-demand charge customers if the basis for allocating capacity charges is not well formed.

We further explore the ability of demand charges to adequately support emerging consumer demand profiles and their potential to integrate with new grid technologies. For example, as the electric vehicle market expands, investors and regulators alike are concerned that demand charges will impact the financial feasibility of vehicle charging stations, particularly at low levels of utilization (Muratori et al., 2019; O'Connor and Jacobs, 2017; Zhang et al., 2017). Modernizing demand charges could also incentivize a new generation of load control technologies and third-party aggregators that seek to orchestrate customer loads to match supply.

The paper begins with an abbreviated history of demand charges in the electric utility industry and the principles from economics that are applied in rate design. The cost shifting consequences of demand charges are then explored through a regression analysis. Potential alternatives to the demand charge are provided to structure the ongoing debate of how to best achieve system goals of an affordable, reliable, and decarbonized grid and fully leverage emerging grid technology.

3.2 Background

Demand charges were first proposed in 1892 by British Engineer John Hopkinson in a very different regulatory context than today (Taylor and Schwarz, 1990). Centralized utilities were struggling to attract commercial and industrial customers, and independent electricity plants comprised over 20% of the marketplace until the 1940s (Neufeld, 1987). Utilities had difficulty competing with the multiple advantages that customers could glean from self-generation. For example, when factories produced excess steam as a by-product, they could use that steam to generate their own electricity. Self-generation occurs without line losses or billing and metering costs which made it difficult for new electric utilities to financially compete with the alternative of self-generation (Neufeld, 1987). When an industrial plant considered their choices of investing in independent generation or signing up with a utility, the biggest cost drivers were the total power they needed to generate (fuel costs) and the amount of infrastructure they would need to acquire (maximum load).

Demand charges were designed to help encourage businesses to shift power requirements toward centralized utilities in order to help utilities overcome the pricing advantages of independent generation and ultimately achieve economies of scale. In order to compete with independent plants, utility rates had to track the costs of their competition rather than establish price signals based simply on their own marginal cost of supply (Baumol and Bradford, 1970; Neufeld, 1987). This was what Bonbright et al. (1961) referred to as value-based rather than cost-based pricing. Demand charges based on a customer's own peak served as a useful pricing mechanism that could help tilt the scales toward the centralized utility alternative while also maximizing the margin or net revenue contribution. The economies of scale possible for a centralized utility provided early electric utilities with a cost advantage. By creating a pricing scheme more aligned with the competition than with their costs, they could lure industrial customers away from self-generation technologies. Relative to a coincident peak framework for demand charges, this value-based pricing framework helped play to the comparative advantages of a centralized system over an independent system, while also maximizing the contribution to net margins.

Demand charges have persevered despite the fact that savings realized through economies of scale in generation largely peaked in the 1970s (Pechman, 2016; Rábago and Valova, 2018). In the United States, the 1970s were characterized by rate design efforts to support the introduction of disruptive technologies and cost uncertainties emerging from the oil embargo, safety delays on nuclear construction after Three Mile Island, and natural gas shortages (Pechman, 2016). Investments in large-scale utility construction were questioned for both political and economic reasons, and efforts towards energy efficiency, demand-side management, and distributed energy resources came more into focus.

While the original rationale for demand charges is no longer as relevant, this rate design mechanism still serves an important role for utilities. Utility capital costs are still driven in part by the size of a customer's maximum load, and demand charges are used to allocate capital costs in establishing rate recovery. Further, the predictability of the revenue stream from demand charges to utilities provides a stable source of revenue. However, as a fairly blunt form of price discrimination, the benefits of demand charges during the earlier sociotechnical transition from decentralized to centralized electricity may be outweighed today by the costs of price distortions (Rábago and Valova, 2018). This is of particular concern given the growth of weather-dependent generation that exacerbates misalignment between system level costs and price signals based on individual customer loads.

In the economics literature, the incentive to cost shift due to consumer price differentiation is a kind of principal-agent problem, and it has been a recurring theme in analyses of market failures in the power industry (Gillingham and Palmer, 2014; Grossman and Hart, 1992). While this reasoning is often used to describe inefficiencies at the individual level like the landlord-tenant split incentive, it has also been used at the firm level to describe inefficient decisions that emerge from the managerial separation of capital and operating costs (Tietenberg, 2009). The incentive for the capital cost group to keep costs at a minimum will negatively impact the operating cost team's ability to minimize recurring expenses, resulting in an inefficient use of resources at the firm. The principal-agent effect may also be at work through the demand charge as decisions from commercial and industrial customers impact residential customers.

This price distortion could limit demand for energy innovation and contribute to curtailment of renewable energy sources. A current example pertinent to utility regulators trying to meet state goals to electrify transportation is the case of electric vehicle charging. Demand charges are designed to assign costs to high demand customers who have spiky demand (i.e., relatively uniform demand with intermittent shorter periods of high demand). Electric vehicle (EV) charging stations have the spikiest possible demand, as they need to provide high levels of on-demand electricity at any time of day. Since traditional demand charges assess costs based on the maximum load that a customer demands over the course of a month, EV charging stations will see a prohibitively high energy cost that may make it difficult for capital investment to be financially viable (Greene et al., 2020; Muratori et al., 2019). Utilities are already experimenting with new pricing schemes for charging stations, such as time of use rate structures that could help to match charging to the availability of power on the grid (Szinai et al., 2020).

Electric vehicle deployment is not the only example of changing electric grid dynamics that are being impacted by outdated demand charges. New technologies such as load-control, battery storage, and self-generation are becoming economically viable for customers of all levels of electricity demand. However, there has been limited market penetration for these technologies, in part, because only C&I customers are incentivized to capture savings through reduced demand charges[6]. Industrial customers in particular have large energy expenses and thus can make larger investments in grid technologies due to shorter payback periods (Park and Lappas, 2017).

Neither a flatter load, nor a lower load-factor, will effectively manage costs in today's energy marketplace. Even as commercial and industrial customers realize savings by smoothing out their load profiles, renewable energy generation is destined to be underutilized, or at least not well compensated, as the match between load and production fails to be well aligned. The alternative is to shape loads to conform to the peaks and valleys of system supply. Loads have the potential to be shaped through dynamic pricing, including capacity price-based alternatives to the traditional demand charges or through managed charging arrangements. The changing nature of the grid begs the question of whether current rate structures should be overhauled with less attention to demand flattening and more on real-time demand-supply matching.

3.3 Methodology

This approach compares customer prices at utilities that derive almost none of their revenue from demand charges to utilities that rely heavily on demand charges for revenue. If costs are assigned to the demand function that are not truly sensitive to actual demand then the demand charge would serve to both save costs and shift costs. Where avoided costs align with the price signal, there are system savings that rightly flow to the

[6] Important exceptions currently exist where the utility offers some measure of managed charging services to help avoid system costs, including upstream wholesale capacity-related charges through controls on storage systems (batteries and water heaters) or managed charging of electric vehicles. Battery storage systems (and potentially EV's in the future) also offer a household resilience benefit that is spurring earlier adoption by residential loads.

responsive customers. But the overhead costs will inevitably be spread between rate classes. When this happens, it follows that customers who do not have an ability to realize cost savings through peak management (i.e., those without a demand charge price signal) would thus be held accountable for a greater share of these grid expenses. This analysis will thus look to see if the degree to which utilities rely on demand charges influence the prices their residential customers pay as compared to commercial and industrial customers.

The analysis explores how the predominant demand charge rate structure in the United States is impacting average residential prices as compared to C&I prices. The ratio between residential and commercial prices, as well as between residential and industrial prices, are both investigated as dependent variables in a series of linear regression models, with the fraction of utility revenue received from C&I demand charges as the main independent variable of interest.

Formally, the empirical specification is:

$$Ratio_{Resi:\lambda(u)} = ß_{0+} ß_1 FRDC_{\lambda u} + ß_2 OwnershipStructure_u + ß_3 Region_u + \varepsilon_u \quad (1)$$

Where u is the index for a utility and λ is the index for customer class. The dependent variable, $Ratio_{Resi:\lambda(u)}$, is the ratio between residential average prices to commercial and industrial average prices within the same utility. The independent variable FRDC is the fraction of overall revenue that a utility derives from demand charges for each customer class (λ) at each utility (u). A positive estimate for α_1 implies that a higher demand charge leads to higher residential prices relative to other customer classes. Dummy variables are incorporated to control for general regional differences in market costs and service (West, Midwest, South, or Northeast)[7], and structural differences in utility management and ownership (investor owned, municipal, or cooperative).

3.4 Data

Utility data is drawn for 2017 from two primary sources. Average customer prices, utility revenue, utility sales, number of customers by class, ownership structure, and location are from form 861 published by the United States Energy Information Administration (EIA, 2017). Utility-specific information about maximum demand charges is from a data set published in 2017 by the National Renewable Energy Laboratory (NREL, 2017). Our sample is restricted to 447 electric distribution utilities that provided data to both NREL and EIA in 2017.

Table 1 summarizes the average price data by customer class used to derive the dependent variables, as well as the fractions of revenue generated by demand charges. This analysis shows that, on average, the demand charge represents a larger percentage of revenue in industrial customer classes as opposed to commercial customer classes. Figure 1 shows the distribution of demand charge pricing across the United States. Northeast utilities have the highest average demand charges while utilities in the South have the lowest.

Table 3.1. Descriptive Statistics

Variable	Mean	Std Dev	Min	Max

[7] The regions were selected based on the United States Census definition of regions Census, U.B.o.t., 1995. Statistical Abstract of the United States, 115th edition ed, Washington, DC.

Maximum Demand Charge	13.1207	7.2116	1.55	59.06
FRDC: Commercial	0.3197	0.1629	0.0294	0.907
FRDC: Industrial	0.4412	0.2512	0.0396	1.3999
Ratio of Residential Price: Commercial Price	1.1399	0.1632	0.5875	2.0266
Ratio of Residential Price: Industrial Price	1.5592	0.4075	0.4195	3.3605

Notes: Number of observations = 447

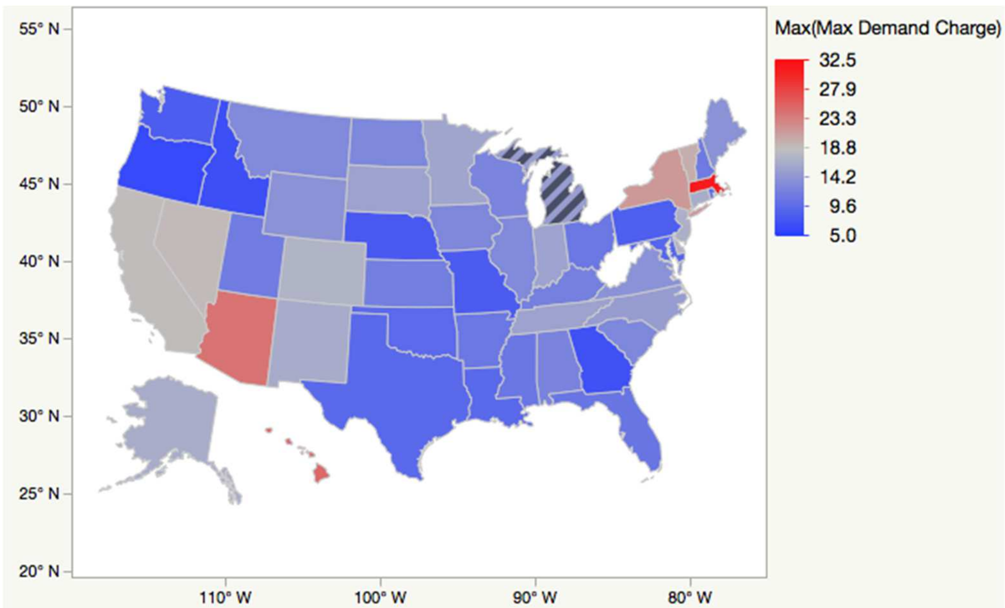

Figure 3.1. Average maximum demand charge by state.

The fraction of revenue that a utility derives from demand charges for commercial and industrial customer classes is obtained by approximating peak demand as twice the average demand of each customer. Since demand charges are simply a pricing premium (unique for each utility) multiplied by the number of kW used during a customer's 15 minute period of peak usage, we can find how much commercial customers are paying in demand charges. We use this utility level data point to calculate the fraction of revenue at each utility that is driven by the demand charge premium that they have set.

In our empirical specification we compare customer prices at utilities that derive almost none of their revenue from demand charges to utilities that rely heavily on demand charges for their revenue. This is based on the assumption that if costs are assigned to the demand function that are not truly sensitive to actual demand then the demand charge would serve to both save costs and shift costs. Where avoided costs align with the price signal, there are system savings that rightly flow to the responsive customers. But the overhead costs will inevitably be respreads between rate classes. When this happens, it follows that customers who do not have an ability to realize cost savings through peak management (i.e., those without a demand charge price signal) would thus be held accountable for a greater share of these grid expenses. This analysis will thus look to see if the degree to which utilities rely on demand charges influence the prices their residential customers pay as compared to commercial and industrial customers.

3.5 Results

The results of two model specifications with and without dummy variables are presented in Table 3.2 for a dependent variable of residential to commercial price ratio, and in Table 3.3 for the residential to industrial price ratio.

Table 3.2. Regression results where the dependent variable is residential: commercial prices.

Commercial Segment: Results of Multiple Regression Analysis						
	Model 1			*Model 2*		
	β	S.E.	***p***	β	S.E.	***p***
Intercept	1.106	0.008	****	0.988	0.018	****
Independent Variable						
Fraction of Revenue from DC	0.133	0.025	****	0.134	0.028	****
Control Variables						
Region - Northeast				0.091	0.031	***
Region - West				0.076	0.015	****
Region - Midwest				0.087	0.013	****
Ownership - IOU				0.098	0.021	****
Ownership - Rural Coop				0.073	0.018	****
Model Fit						
	Model 1			*Model 2*		
N	1247			1175		
R^2	0.0226			0.093		
Adj R^2	0.0218			0.089		
Prob > F	p < .0001			p < .0001		

Notes: IOU and Rural Coop are dummy variables and are compared to Municipal Utilities.

** p<.1. ** p<.05. ***p<.01. ****p<.001*

The regression results in model 1 in Table 3.2 show that the estimated coefficient of the fraction of revenue derived from commercial demand charges is positive and significantly associated to the ratio of residential prices to commercial prices. This suggests that when a utility relies more on demand charges from commercial customers for their revenue then their residential customers are likely to pay higher rates relative to their commercial customers. When the model controlled for region and ownership structure in model 2, the relationship was much stronger, indicating that the location of the utility and ownership structure improved the model considerably. The regional dummy variables indicated that utilities in the South were likely to have the lowest FRDC while utilities in the Northeast had the highest. In our partial tests for significance, each of the control variables had significant F Ratios with a significance less than .005. Results further indicated that municipal utilities had the lowest FRDC while Investor Owned Utilities had the highest. While all of these control variables shifted the y-intercept, they did not influence the strength of the relationship between FRDC and residential prices. We tested for interaction effects between the independent variable and control variables and the results were not significant. In our whole model test the F Ratio was 20.056 with a corresponding p-value of less than .0001 so we were able to reject the null hypothesis.

Table 3.3. Regression results where the dependent variable is the ratio of residential to industrial prices.

Industrial Segment: Results of Multiple Regression Analysis						
	Model 1			*Model 2*		
	β	S.E.	***p***	β	S.E.	***p***
Intercept	1.310	0.029	****	1.289	0.050	****
Independent Variable						
Fraction of Revenue from	0.542	0.061	****	0.609	0.061	****
Control Variables						
Region - Northeast				0.063	0.080	
Region - West				-0.159	0.049	***
Region - Midwest				-0.147	0.036	****
Ownership - IOU				0.176	0.058	***
Ownership - Rural Coop				0.078	0.044	
Model Fit						
	Model 1			*Model 2*		
N	509			466		
R^2	0.136			0.233		
Adj R^2	0.1344			0.223		
Prob > F	p < .0001			p < .0001		

Notes: IOU and Rural Coop are dummy variables and are compared to Municipal Utilities.

** p<.1. ** p<.05. ***p<.01. ****p<.001*

The results for the industrial sector in Table 3.3 reveal an even closer relationship than that uncovered in our investigation of the effect of the commercial demand charge. In this model the ratio of residential prices to industrial prices was also highly correlated to the fraction of revenue that a utility derives from demand charges but resulted in a higher F Ratio of 23.191 with an associated p-value of less than .0001. In our partial tests only some of the control variables were significant: location in the Midwest or South and an IOU ownership structure. Location in the Northeast and a Cooperative ownership structure were not significant, given other terms in the model. The R^2 of this model was 23.36% as opposed to 9.32% for the commercial model. These results suggest that industrial demand charges are much more likely to effect residential prices than commercial demand charges.

These results suggest that the more a utility relies on industrial demand charges, the higher their residential rates will be relative to their commercial and industrial average rates. While demand charges at the commercial level do significantly impact the ratio of residential prices to commercial prices (Table 3.2), these results are weaker than the relationship observed in Table 3.3. This is counter to the original hypothesis which predicted that commercial and industrial demand charges would be equally related to residential price variability.

This result makes sense because industrial customers, on average, have much higher levels of demand due to the fact that they manufacture goods (unlike commercial customers) (see Table 3.4). Purchasing large quantities of power enables industrial customers to achieve economies of scale, and the average industrial customers generates considerably more revenue for a utility than the average residential customer.

Furthermore, manufacturing companies have predictable loads that can be dramatically impacted by a change in process. Investing in energy-efficient equipment or load flattening technologies such as battery storage can dramatically shift or flatten their load resulting in a quick return on investment. Since industrial customers have higher average electric costs they can financially rationalize investment in more expensive grid technologies. Industrial customers will also more commonly have dedicated management and/or engineering staff capable of providing added rigor to these decisions. Industrial customers are thus more capable of responding to utility signals, and the data supports the hypothesis that the response of industrial customers to demand charge signals is what is ultimately driving the shift of fixed costs onto the residential segment.

Table 3.4. Distribution of average revenue per customer by customer type (in units of 1,000).

Customer Segment	Min	Max	Avg	Std Dev
Residential	.7109	3.3076	1.4606	.3568
Commercial	.75	52.4583	5.862	4.458
Industrial	.4	72449.9	808.400	3587.26

Additional conclusions can be drawn from the relationship between the dependent variables and the control variables such as region and utility ownership structure. There is considerable debate in the literature regarding the impact of utility structure on residential prices, with the majority of studies finding that investor owned utilities are correlated with higher residential prices (Kwoka Jr, 2005; Meade and Söderberg, 2020). The data in our results partially supports these findings but also suggests that cooperative ownership may also result in higher residential rates relative to commercial and industrial customer classes. Rural cooperatives need to service large territories with a customer base that is not highly concentrated. Infrastructure costs are thus spread out across a smaller pool of clients, which could explain why municipal utilities were found to have relatively lower rates than rural cooperatives. In Table 3.2 the β for both investor-owned utilities and for cooperative distribution utilities was positive, indicating that municipal utilities have lower residential prices on average. In the study on industrial rates (Table 3.3), the β's for both investor ownership and cooperative ownership were positive but only the variable for private ownership (IOU) was significant. Consistently, the β's for investor-owned utilities were higher than the β's for cooperatively owned utilities, supporting the existing research on the subject but adding the additional information that rural cooperatives may also have relatively higher residential rates as compared to municipal utilities.

The region in which the utility was located was also significantly correlated to the relative residential price in many of the results. In both tables, residential prices were higher in the Northeast as compared to what utilities charged their commercial and industrial customers.

3.6 New Options for the Demand Charge

The goal of demand charge reform is to more clearly align utility cost and pricing signals in order to reduce overall system costs. This will be all the more important if, as the authors believe, lower system costs better position utilities to succeed with environmental and social equity goals. Here we evaluate existing research on alternatives to the traditional demand charge to assess strengths and weaknesses for grid operators and electricity consumers. Following the example set by (Passey et al., 2017) in their critique of the cost-reflectivity of the demand charge, this research specifically analyzes the selection of an appropriate tariff structure. While calculating incremental costs of service and setting revenue recovery levels appropriately are also important rate design priorities, this research does not include these additional elements. Rather the purpose of this discussion is to shed light on static and dynamic pricing strategies that recent advancements in technology have made possible and summarize alternative options for the structure of a new demand charge tariff. Table 3.5 highlights the opportunities and challenges for a selection of strategies discussed in turn below.

Table 3.5. Overview of approaches for improving demand charges.

Strategy	Opportunities	Challenges
Wider Implementation of Residential Demand Charge	• Align utility costs with customer pricing • Improve load factors • Reduce utility exposure • Reduce subsidies for customers with high demand • Built-in productions for small customers	• Demand response fatigue • Potential over-investment in infrastructure
Demand Charge Preferential Rate	• Makes EV charging station business model viable • Improve ability for states to meet GHG policy goals • Open EV charging station revenue streams to utilities	• Doesn't solve demand-related inequities for existing customers • Risk that utilities may not recover costs • EV charging station model could crumble once term ends
Reduce/Eliminate Demand Charge Ratchet	• Align customer costs more closely with system costs	• Weaken important signals at sub-system level

Strategy	Opportunities	Challenges
Divide Demand Charges into Sub-components	● Align customer costs more closely with system costs ● Enable C&I customers to reduce their overall costs ● Invigorate the energy storage marketplace to drive innovation	● Adds additional complexity ● Switching costs high for clients with sunk costs ● Utility costs may not all be recouped
Sharpen Time-of-Use or Time-Varying Pricing	● Could serve as a complement to existing rate structure, minimizing amount of change required ● Incentive for C&I customers to shift load based on real costs ● Open market to aggregators	● Smaller customers might have difficulty responding to signals ● Does not address residential market ● Adds complexity to pricing scheme
Enabling Aggregators with load management and dynamic pricing	● Builds on precedent of rate discounts for demand side flexibility ● Take advantage of the proliferation of smart connected devices (IoT) ● Creates a predictable revenue stream for aggregators ● Reduction of system complexity for the utilities ● Ability to inject load or generation at different points in the network	● Utilities lose some control of their customer relationships ● Risk of unethical aggregators

3.6.1 Wider Implementation of the Residential Demand Charge

There is debate in the literature over the advisability of a residential demand charge amidst widespread recognition that consumers are becoming more actively involved in the energy system and need to be provided with access points to reduce system costs (Brown and Faruqui, 2014; Hledik, 2014; Schittekatte et al., 2018; Simshauser, 2016). The benefits of residential demand charges are enumerated by Hledik (2014) and include aligning utility costs with customer pricing, improving load factors, reducing utility exposure in situations where customers reduce overall consumption but not demand, reducing subsidies for consumers with high demand, establishing regulatory precedent, and creating built-in protection for small customers. These diverse advantages build a strong argument to support more widespread use of residential demand charges.

In practice, however, there are numerous potential drawbacks that have been uncovered through pilot programming. Residential consumers are typically less centered on their pursuit of seemingly rational economic outcomes, even when price signals are well aligned to produce outcomes that benefit both consumers and the system (Thaler and Sunstein, 2009). Pilot programs have revealed that residential customers often respond to pricing signals initially, but their response are muted and degrade over time, a condition described as demand response fatigue (Kim and Shcherbakova, 2011). There is also the concern that residential customers would be too responsive and invest heavily in technologies such as batteries before they achieve economies of scale, a result that would aggravate the sunk cost recovery problem (Schittekatte et al., 2018). The risk of sending the wrong signal to customers or of customers disregarding or overreacting to the new pricing scheme could undermine the appeal of a capacity-based structure applied to residential customers.

Ultimately some form of capacity related price signal may be appropriately extended to residential customers. For example, a fairly complex rate structure may make sense if there is either embedded supporting technology (e.g., onboard or charging equipment control of EV charging), or if more complex rates are coupled with either new third-party agents that can manage the complexity for customer benefit or the utility functioning in that same capacity.

3.6.2 Demand Charge Preferential Rate

Another option to consider is a demand charge preferential rate, which would provide relief from traditional demand charges for specific types of customers for a set period of time. In this scenario, demand charges would simply be waived in order to allow new businesses like EV public charging stations to gain a foothold in the marketplace. This would better enable utilities and states to meet policy targets for greenhouse gas curtailment while also opening up revenue streams to utilities that want to take advantage of the increased demand required by an electrified vehicle fleet.

This rate structure has the potential to become a key component of a green infrastructure development plan. A short-term demand charge relief option could be extended to all businesses to help spur electrification of loads like heat and transportation. In exchange for curtailing energy use during system peaks, small businesses could avoid demand charges as long as they committed to covering their aggregate marginal costs. The preferential rate structure could be particularly impactful to businesses that will ultimately require greater capacity utilization (i.e., higher load factors) but only expect to achieve modest overall levels in their formative years. As a practical matter, this rate structure often exists in the form of a uniform energy charge with embedded capacity-related costs, but with a trigger that requires mandatory participation to a rate with a demand charge for customers above a certain energy or demand requirement.

Despite the transformative potential of demand charge preferential rates, challenges still remain. While this option would provide a path forward for new types of business models, existing C&I customers would still be limited in their ability to leverage new technology to modulate their demand to reduce their prices as well as overall system costs. These businesses may have already invested in technology to flatten their demand, so even if they were offered this option they may have embedded or unavoidable commitments that center on the old design. Utilities would also be at risk, as these new or shifting loads may still be significant cost drivers that challenge the utility's ability to recover the cost-of-service. Lastly, public EV charging stations and other emerging business models that could leverage this plan could find themselves in a difficult place when their term of preferential rates concluded. Despite the risks associated with this path, if designed correctly it might perform, at the very least, as a stopgap measure to address the imminent rate structure challenges related to EV charging stations.

3.6.3 Reduce or Eliminate the Demand Charge Ratchet

Demand charge ratchets ensure that utilities are able to recoup demand related costs from their C&I customers throughout the year, and not just when the client's demand is at its peak. A demand charge ratchet ensures that a customer will typically pay 50-90% of their maximum annual demand charge every month for the remaining eleven months. Since a utility has to build enough infrastructure to support the annual peak demand of a customer, this ratcheting system has been a reasonable strategy to entice customers to invest in load management and reduce their annual peaks.

In the current rate environment, however, avoidable system costs are more likely to be tied to upstream costs than to a customer's annual load. These upstream costs can be avoided or at least substantially reduced for utilities with effective price signals passed to their retail customers. In New England, for example, these costs include wholesale market rates designed to recover the embedded and operating costs of the pooled transmission facilities through Regional Network Service charges. Under the existing design, these charges disappear at the end of each monthly billing cycle. Also, the Forward Capacity Market costs could be more effectively managed, or even avoided, by sending retail customers a more targeted, dynamic price signal on an annual basis. The majority of capacity-related costs occur at the wholesale and bulk transmission system level, not the sub-system level (which includes distribution or sub-transmission costs). Thus, ratcheting may make sense for utilities to recover costs at the sub-system level, but it is no longer a compelling cost recovery mechanism to recoup wholesale and bulk transmission system level costs. Given that sub-system costs are an increasingly minor component of a utility's overall expenses, it makes sense to re-evaluate demand ratchets in order to more closely align avoidable utility or system costs with price signals.

3.6.4 Split Demand Charges into Peak and off-Peak Demand Charges

Another option is to narrow the timeframe where peak demand prices can apply and charge customers based on their marginal system costs via peak demand charges and on their marginal sub-system costs based on off-peak demand charges. Many utilities apply the same demand charge over all periods of the day and all seasons of the year, despite the fact that system costs differ substantially based on fluctuating generation and demand. For example, on the utility side, demand-related system costs in New England are primarily driven by load that occurs between 5 pm and 10 pm, although the growing penetration of solar PV net metering is shifting peaks beyond daylight hours and narrowing that time frame to between 7 pm and 10 pm. Therefore, the traditional demand charge could sensibly be divided into two sub-demand charges: peak and off-peak. Peak demand periods could be limited to time frames where demand is most likely to trigger system-level costs, such as the monthly or annual peak. Lower off-peak demand periods could be shifted to times when demand is most likely to impact distribution-level costs. By splitting the demand charge into at least two rates, and thus narrowing the associated time frames, C&I customers would be able to take advantage of new load-shifting technology.

There is currently little financial incentive for commercial and industrial customers to shift their load for short periods of time. However, a more targeted demand or capacity-related charge would create a marketplace for storage technology that could shift customer demand during system and sub-system peaks. Since the cost of a battery is driven by its capacity, relatively inexpensive batteries could then serve as an important cost-saving mechanism for C&I customers. By reducing the timeframe associated with reformed demand charges, the benefit to the grid and customer could become better aligned with priorities related to decarbonization and the proliferation of renewable energy technology. If coupled with other reforms for renewable energy compensation, emerging renewable energy technology manufacturers could also see great interest in their products and services, opening up a new marketplace for storage technology virtually overnight. Further, customers could access new pathways to leverage emerging technology and ultimately reduce overall system costs.

3.6.5 Sharpen or Refine Time-Of-Use or Time-Varying Pricing

Time-of-use and time-varying pricing could complement existing capacity-related charges by aligning customer rates with utility expenses. By exposing C&I customers to some of the cost signals at the system level, clients could be motivated to manage their own loads or sign up with an aggregator who can respond to utility signals for the customer and pass along a percentage of the resulting savings. The level of customer exposure is a sensitive issue, but if participation was not mandatory then this rate design strategy could open the marketplace to aggregators and provide a useful foundation for building a more responsive demand landscape.

Existing research on sharpening time-of-use rate structures exhibits mixed results in reducing system costs and finds a pattern of conservation rather than load shifting in customer response. Previous research indicates that such pricing typically reduces peak by less than five percent (Newsham and Bowker, 2010). Another study on customer behavior in a time-of-use rate environment determined that customers were more likely to respond to these refined signals with conservation strategies as opposed to load shifting (Miller et al., 2017). Thus, if one of the goals of re-envisioning the demand charge is to create a more dynamic, responsive customer base then this approach would not be the best fit.

3.6.6 Enabling Aggregators through Utility Load Management and Dynamic Pricing

Rate discounts on electricity are an established strategy for utilities to incentivize consumers to respond to utility signals. In exchange for demand side flexibility, the customer is provided a financial incentive. This type of pricing signal has been leveraged to advance goals related to distribution system automation, defined by the Institute of Electrical and Electronics Engineers as a system that allows electric utilities to monitor, operate, and coordinate the components of their system in real time from remote locations (Gupta and Varma, 2005; Muttaqi et al., 2015).

For example, interruptible load discounts are offered to ski areas in Vermont and other large industrial customers, guaranteeing that the utility can reduce some of their system load when system costs are high. Ripple-controlled systems and clock-managed services have also been offered to residential and small commercial customers to spur demand side curtailment of smart devices like water heaters, washers and dryers, thermal loads, and EV charging systems (Roux et al., 2018). Ripple control systems are used worldwide and they work by using a high frequency signal to remotely shut off attached devices until the signal is disabled. Clock-based water heater systems rely on a more distributed time clock that similarly shuts down the load and turns it back on.

However, the true impact of residential demand side management stems from its aggregation (Carreiro et al., 2017). Energy management system aggregators have stepped forward to serve as an intermediary between the utility and their rate base. In order for this business model to be sustainable, time varying price signals need to be made available, at least on an optional basis. This will better align rates with system costs to provide a joint and collective benefit to end-users as well as the utility system while encouraging the participation (and profit) of new agents. Aggregators can provide significant services to a system operator, including the reduction of system complexity and integrating distributed energy resources that can precisely inject generation or load onto certain points of the network (Faria et al., 2018).

A major hurdle to the development and deployment of system aggregators is the lack of adequate regulatory frameworks (Carreiro et al., 2017). A rate structure that more broadly provided incentives for consumers to sign up with aggregators could provide significant benefit to grid operators and rate payers alike. By considering a broader, more inclusive rate discount based on flexibility, new marketplaces for energy management system aggregators could emerge to help utilities manage their distribution networks more effectively.

3.7 Conclusions

Neufeld (1987) describes the demand charge as a "modern relic" from a very different type of electric grid. Demand charges continue to serve an important role in assisting utilities with recovering fixed, embedded and overhead costs necessary to meet the utility's revenue requirements (total cost-of-service), but changes to the system are widening the gap between cost containment from load management and the relatively undifferentiated utility load profiles that demand charges encourage. As utility costs are driven increasingly by forward-looking, avoidable system level cost drivers like capacity charges and management of the distribution level costs, sub-system demand at the customer level becomes increasingly relevant to a typical utility's bottom line, and ultimately cost containment and lower rates. Timing and flexibility of loads now has a much more significant impact on a utility's costs.

Our contention is that demand charges in their current form provide little incentive to manage loads for system benefit, and may also be hampering diffusion of innovative energy technologies (Gillingham and Palmer, 2014). When C&I customers make investment decisions based on pricing signals that don't align with system costs, current objectives for achieving greater affordability, reliability and decarbonization are undermined.. Our analysis found evidence of a strong relationship between demand charges and residential prices. This is to be expected, and might even be the desired result, if demand charges and industry customer responses aligned with avoidable system costs. However, given the state of current heavy reliance of fully allocated cost of service studies which mix both direct and embedded costs into the same demand buckets, there are likely unintended shifts in the attribution of costs to customer classes (Morgan and Crandall, 2017). The results of this research indicate that some of this cost shifting may have a more significant impact on residential customers than other customer classes.

The model also included other predictor variables that have been associated with an increase in retail rates. While utility region did exhibit some significance in our models, the fraction of revenue that a utility received from demand charges was consistently more important. Limited results suggest lower rates in the Midwest which could be related to the proliferation of inexpensive wind power, but many of the regional variables did not prove significant (Quint and Dahlke, 2019). It was thus important to control for region but the impact of the demand charge proved more relevant to our research into drivers of relative residential prices.

We also controlled for utility ownership structure in this study. The results we recorded supported existing conclusions regarding higher relative prices for consumers served by investor-owned utilities (Kwoka Jr, 2005; Meade and Söderberg, 2020). However, customers of cooperative utilities also appear to experience pricing premiums relative to customers of municipal utilities. Higher prices overall are understandable as rural cooperatives need to build more infrastructure in order to serve their widely distributed customer base and more costs need to be spread over a smaller number of customers. It is particularly important to attribute costs correctly in rural areas, as rural residential customers are often extremely vulnerable to fluctuations in electricity prices.

In Vermont – the most rural state in the country by census definition – an average rural, low-income household can spend up to a fifth of their income on energy, distributed across transportation (45%), thermal (35%), and electricity demands (20%) (Sears and Lucci, 2019). The increased ratio of residential prices relative to the prices of other customer classes, and the sensitivity of this data point to the fraction of revenue that a utility receives from demand charges, implies that rural customers may be particularly vulnerable to cost shifting from demand charges.

This analysis is timely in light of existing trends in the power industry. As storage technology continues to achieve economies of scale and becomes more affordable, industrial customers will continue taking steps to flatten their loads to dramatically lower their demand charges. Utilities risk losing significant demand charge revenue when their industrial customers adopt new technology. These sub-system savings will not be able to offset the more significant costs related to the Forward Capacity Market and Regional Network Service. Enabling aggregators with load management and dynamic pricing could be the most promising direction of the options included in Table 3.5, but more research would need to be done to compare the different strategies and learn what approaches other countries are taking to fairly allocate costs amongst their customer classes.

Utilities are also on the threshold of a surge of demand from electric vehicle diffusion. Without a clear rate mechanism to incentivize charging vehicles when power is abundant and restrict charging when power is limited, utilities will have a difficult time harvesting value for lower rates from this new stream of revenue. The proliferation of electric vehicles and the importance of this new technology to mitigate climate change makes this an urgent issue.

One area for future research is the impact of the existing rate structure on renewable energy entrepreneurship. Given a limited marketplace for storage systems that can shift power for 2 to 4 hours, renewable energy and storage entrepreneurs are not seeing the level of demand that could propel their research and design efforts to the next level. Aggregators are another group of renewable energy entrepreneurs who can capture limited value for either customer or system benefit from the current structure of the demand charge. The market signals that would allow them to orchestrate demand for utilities are often weak or short-lived, adding high levels of risk and uncertainty to their business models. Despite the proliferation of smart devices in the household, residential aggregators have yet to harness the potential for flexing demand, a finding attributed to the lack of a forward-looking regulatory framework (Carreiro et al., 2017).

The goal of this analysis was to learn if industrial customer demand charges were highly correlated with high residential rates in order to see if demand charges were shifting costs onto residential consumers. The possibility exists that industrial customer demand charges are shifting costs onto commercial customers as well, as their high energy budgets and dedicated technology personnel enable them to invest more in behavior that could reduce their demand charge payments. This relationship could be explored in future research as well.

Despite the myriad challenges with the existing demand charge structure, there are exciting opportunities for developing a new type of demand charge that is less rigid and more effectively aligns customer prices with system costs. As the grid becomes more dynamic and all classes of customers are increasingly capable of engaging with their utilities either through self-generation, storage, or smart devices, room will need to be made to invite these new stakeholders to participate in the grid. The nature of this invitation is critical, and a key element is a clear pricing signal that reflects the true costs that utilities pay to provide energy in a grid increasingly powered by renewable energy generation.

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Chapter 4

What Drives Renewability Orientation? An Examination of Environmental Consciousness in the Power Industry

Bonnie Pratt

Abstract

There is wide variability in how electric distribution utilities approach the energy system transition toward more renewables. While some utilities lean into the transition, others take a more conservative approach. This analysis measures the impact of state level policies, rurality, firm ownership structure, and the gender of the firm manager to test hypotheses about which conditions are most likely to support a utility's commitment to renewables. This research is grounded in the institutional resource-based perspective and fills a gap in the entrepreneurial orientation literature by addressing innovation in a regulated industry. Firm performance in the power industry is measured as the percent of renewable energy in a utility's fuel mix and the commitment to renewables and efficiency expressed in planning documents. We use a database of 170 electric utilities in the United States and computer-aided text analysis (CATA) to understand which utility characteristics were most likely to predict a proactive positioning towards renewables. Results indicate that rurality, deregulation, and the entrepreneurial orientation of a utility as expressed through their Integrated Resource Plans helps to explain a significant amount of variability in the environmental consciousness of distribution utilities.

4.1 Introduction

Why do some electric utilities lean into the transition from fossil fuels to renewable energy while others resist change? The power industry is in upheaval as user preferences change, generation loses predictability, and the electrification of industries like transportation and agriculture are poised to exert pressure on an already stressed regime. Firm performance measures have expanded from a singular focus on providing reliable, least cost power to now include meeting policy goals for larger renewable energy shares. Some utilities are taking a defensive stance and resisting decarbonization, while others lean into a future based on a decentralized, decarbonized, and digitized grid. It is critical that we achieve greenhouse gas reduction goals in our energy system (Christoff, 2016) and electric utilities are in a position to either support or hinder those goals.

This research seeks to uncover what market, firm, or individual factors are most likely to influence how a utility approaches renewable energy generation and purchases. Utility plans for integrating renewables into their power supply mix are laid out in public documents known as Integrated Resource Plans (IRPs). These comprehensive documents detail a utility's current fuel mix and convey their strategy for generating energy in the future. The language that the authors use to describe their plans can provide insight into their strategic orientation (i.e., (Short et al., 2010)), and reveal how the utility is positioned to meet, exceed, or resist the transition to renewable energy. In this paper we introduce Renewability Orientation (RO) as a metric to assess a firm's positioning towards renewables in their planning documents. By employing computer-aided text analysis (CATA) we were able to quantitatively assess the level of RO for 170 electric utilities in the United States. To assess the utility orientation towards renewables and efficiency we created a new CATA dictionary based on the combined glossaries of the American Council for an Energy Efficiency Economy (American Council for an Energy-Efficient Economy, 2019) and Clean Energy Resource Teams (Clean Energy Resource Teams, 2019). RO scores were compared to fuel mix data for 148 of the 170 electric utilities in our database to objectively assess utility positioning in the energy system transition.

In this research, several antecedent influences upon the commitment to a strategic orientation emphasizing renewability are explored. These antecedent influences are identified and categorized based upon institutional theory. In resource-based institutional theory, firm heterogeneity results from the way that firms manage their institutional context (Oliver, 1997). This context consists of both the internal culture of a firm and the external conditions within which it operates. The resource decisions that firms make while navigating these forces is deeply related to their ability to achieve a sustainable competitive advantage. Building on Oliver’s three-level framework, we identify inter-firm level factors that could influence a utility’s strategic orientation such as state-level policies and demographics. Firm-level factors such as firm ownership and age as well as individual-level factors like the tenure and gender of the manager are also explored to understand the internal institutional context of electric utilities. This theoretical framework scaffolds our analysis of firm heterogeneity.

Oliver’s three-level framework complements existing research on sociotechnical transitions, adding definition and structure to the regime level of Geel's Multi-Level-Perspective (Geels, 2005). Geels research suggests that sociotechnical transitions occur when new innovation arising from the niche level applies pressure to the existing regime while at the same time broad trends such as weather events and social activism apply additional pressure on the regime. The combined effect of niche and high level sociocultural pressure is that the regime is forced to change and convert to a new normal. Oliver’s research is mainly concerned with the performance of businesses and, at the regime level in a sociotechnical transition, some businesses are able to adapt to sociotechnical change and be successful while others fail. Oliver's schema creates a useful platform for understanding how different factors influence the behavior of regime level stakeholders during a sociotechnical transition.

The study begins with a review of the wide body of literature dedicated to the emergence of renewability orientation as a central organizational goal, grounding our discussion and description within resource-based institutional theory. In a regulated industry, proposed drivers of renewability orientation, such as firm’s entrepreneurial orientation (EO), are manifested a bit differently than within private enterprise, and the idiosyncrasies of the United States power industry are elaborated upon to explain how drivers of renewability thought and action are manifest in an industry with a guaranteed rate of return. The data are then analyzed to determine what inter-firm, firm, and individual (managerial) level factors are indeed related to RO and the percent of power a utility derives from renewables. The paper concludes with a discussion of how these results can direct policy makers and utility leadership to catalyze the energy system transition

4.2 Theoretical and Contextual Background

The electric power industry is undergoing an institutional shift, defined as the moment when an industry’s existing rules for competition are changed as a consequence of new regulatory frameworks, technology standards, or business models (Bohnsack et al., 2016). In the traditional business model, utilities receive a guaranteed rate of return on their investments in energy infrastructure, drastically reducing the financial risks of investing in traditional energy generation and transmission technologies. However, new innovations, mounting social pressure to decarbonize, and the trend of customer ownership of generation resources are disrupting the certainty of this revenue model (Geels et al., 2017; Richter, 2012). As the changing characteristics of the electricity marketplace influence decisions about resource acquisition, resource-based institutional theory provides a useful framework for organizing the different levels of variables that might impact a utility's willingness to lean into the energy system transition.

(Oliver, 1997) proposes a resource-based institutional theory with three different levels of inquiry that could impact decision-making: individual, firm and inter-firm. At the inter-firm level, public and regulatory pressures can have a profound impact on business decisions (Engelen et al., 2015; Sarzynski et al., 2012). For electric utilities, state rurality, market dynamism and renewable portfolio standards (RPS) can all significantly impact a utility's engagement with the transition to renewables. For example, rural areas have more land available for installing renewable energy infrastructure and are thus more likely to derive power from renewables (Marsden, 2016). Utilities that operate in states with higher rural populations could therefore be expected to derive more power from renewables. Policy decisions such as opening up the electric marketplace to competition between utilities and requiring a percentage of power to come from renewables could also influence a utility's commitment to renewables (Sarzynski et al., 2012). Firm level variables including size and ownership structure may also influence decision-making processes (Chen and Hambrick, 1995; Wales et al., 2011). In the power sector, firm age and ownership structure could also impact a utility's strategy for integrating renewables into their power supply mix. While many firms have been established for decades in uncontested marketplaces, newer utilities such as Community Choice

Aggregators, a type of municipal utility, are emerging in competitive markets and may use environmental consciousness as a strategy to attract customers (Jones et al., 2017). Finally, at the individual level, factors such as the CEO's experience in the power industry or gender may also play an important role in influencing a utility's environmental consciousness. In the renewables literature, recent studies suggest that women may be more likely to invest in clean energy technologies than men when in corporate leadership positions (Allison et al., 2019).

Each of these levels has the potential to influence a firm's renewability orientation, defined as the percentage of linguistic emphasis upon renewable energy and energy efficiency within a utility's espoused Integrated Resource Plans. Utilities with a higher level of renewability orientation will use a higher percentage of words related to renewables and efficiency in their planning documents than utilities that are less focused on decarbonizing their power supply. In the context of the power industry, a progressive utility will lean into the energy system transition, transitioning generation resources away from fossil fuels in order to meet or exceed policy-driven goals for decarbonization. RO will manifest as a willingness to invest in renewable energy and charging infrastructure, support customer investment in distributed storage and solar, fund programming related to energy efficiency, and experiment with new technologies.

In order for the power industry to evolve into a more decarbonized, decentralized and digitized system, new technologies must be developed, tested, implemented, and ultimately achieve economies of scale. As the sociotechnical transitions literature suggests, early versions of transformative innovations need to be cultivated in protective niche spaces (Geels, 2005; Smith and Raven, 2012). Electric utilities must see a need for change and be willing to push past complacency and embrace an RO. Utilities must also have an appetite for experimentation, as the "used and useful" clause penalizes utilities when promising innovations do not add value as predicted (Brunekreeft and McDaniel, 2005). In the context of the current sociocultural transition, the entrepreneurial orientation of an electric utility should therefore predict the level of RO that a utility exhibits. This orientation should manifest as both an increased amount of language relating to renewables and energy efficiency as well as decarbonization in terms of a higher actual percentage of power from wind, solar, geothermal, hydro, and biomass in the utility's power supply mix. In order to capture this behavior, in addition to RO we also examine each utility's percent of power from renewables in its fuel mix.

In the next section we examine how factors at three levels of analysis are likely to lead to an increase in RO. In doing so, we provide insight into the critical institutional resource-based factors which drive a utility's emphasis upon renewability within its strategic orientation.

4.3 Hypothesis Development

4.3.1 Institutional Resource-Based Theory

While many studies focus on one specific level of analysis when examining firm heterogeneity, Oliver (1997) makes the case that factors at the inter-firm, firm, and individual levels are all important to consider, ideally within the same study. Oliver's organizational framework is particularly well-suited to an analysis of renewability in the power industry because there are profound differences in the institutional context of utilities at each of these three levels. In this research, we select variables at each level with the potential to influence renewability orientation and actions.

Interfirm Level: In a highly regulated industry like the power industry, policies can vary substantively by geographic variables such as the state of operation, which may profoundly impact the firm's strategy. When firm revenue is determined as a guaranteed rate of return on investments that meet with regulatory approval, success depends upon the firm's ability to meet regulatory standards, which can vary significantly across states. For example, some states require renewables to represent a certain percentage of a utility's fuel mix while others make no such demands. By comparing how state-level regulations strengthen or mitigate the environmental consciousness of a utility we can better more fully comprehend how the institutional context of a firm's operating environment impacts their renewability orientation. In addition to variations in policy design between states, demographic disparities such as the rurality of a state may also impact a utility's positioning towards renewables.

Firm Level: Due to the regulated nature of the industry there are discrete differences in firm culture and organization across electric utilities. In the power industry, most utilities are structured in one of three ways: investor-owned, municipally owned, or cooperative. This ownership structure may determine how involved customers are in decisions about their electric system. Rural cooperatives and municipal utilities typically serve a single city and decisions about siting and fuel mix are informed at least in part by community engagement (Stephens et al., 2017). Investor-owned utilities, on the other hand, tend to be much larger and potentially more sensitive to investor priorities as they make resource acquisition decisions. We wanted to understand how firm ownership structure would influence renewability orientation. We were also interested in the link between firm age and institutional conformity.

Individual Level: The actions of top executives can have a profound impact on the trajectory of a firm (Finkelstein et al., 2009). We were interested to see how the gender and tenure of the CEO might influence utility positioning toward renewables. This traditionally masculine field is beginning to open up leadership positions to women but there are still limited examples of female leadership in the power industry (Cook, 2018). Prior research suggests that female led firms are more innovative and likely to champion environmental action in the workplace (Allen et al., 2019; Pearl-Martinez and Stephens, 2016). There is a growing body of literature on the influence of gender on entrepreneurial orientation (Goktan and Gupta, 2015; Lim and Envick, 2013; Runyan et al., 2006). We were interested to see how gender impacted firm performance as expressed through the use of RO and the integration of renewables into a utility's fuel mix.

CEO tenure can also impact the level of renewability orientation that a firm expresses. Research on family firms has found that after about 15 years, a CEO begins to display less entrepreneurial orientation, an effect that occurs at a faster rate in non-family firms like electric utilities (Boling et al., 2016). Prior researchers have applied institutional theory to suggest that increased exposure to institutional norms will make a CEO more likely to exhibit isomorphism and less willing to innovate after a mid-point in their career (Hambrick et al., 2004; Hambrick and Fukutomi, 1991). Our data set was uniquely suited to test hypotheses about the effect of CEO tenure on a firm's willingness to innovate.

Figures 4.1 and 4.2 illustrate how we approached this analysis of heterogeneity in the power industry. We selected eight sets of hypotheses across all three of Oliver's levels in order to build our model. This is a classic example of a moderator model where predictors, moderators, and predictors crossed with moderators, all comprise discrete hypotheses (Baron and Kenny, 1986). Figures 4.1 and 4.2 delineate the ways in which inter-firm, firm, and individual characteristics could influence the amount of power that a utility derives from renewables.

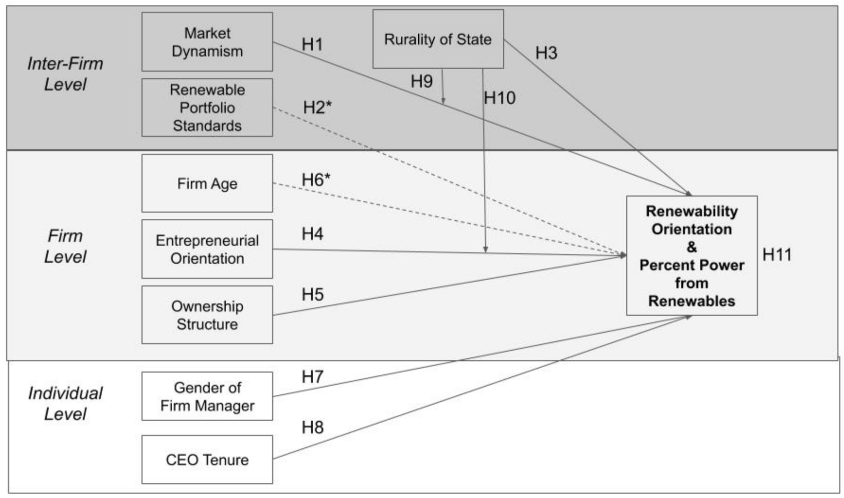

Figure 4.1. Conceptual Framework.

** Renewable Portfolio Standards are only hypothesized to impact percent power from renewables. Firm age is only hypothesized to impact renewability orientation. These are the identifying variables for our two structural equations.*

4.3.2 Outcome Metrics

Renewability Orientation: This new metric, Renewability Orientation, makes sense within the context of the power industry because firm performance is partially defined as the degree to which a company has converted to generation from renewables. More entrepreneurial, innovative utilities will prioritize renewable energy generation and energy efficiency in their planning efforts. The degree to which utilities discuss renewable energy and energy efficiency therefore magnifies the effects illuminated by the traditional EO analysis, which is not industry specific. This new dictionary was constructed by combining non-generic terms from the glossaries of the American Council for an Energy Efficiency Economy with the glossary from the Clean Energy Resource Teams (American Council for an Energy-Efficient Economy, 2019; Clean Energy Resource Teams, 2019).

Renewability orientation is similar to sustainability orientation but different enough to merit a separate metric. The five point scale used in research on sustainability orientation refers to attitudes towards environmental protection and social responsibility (Kuckertz and Wagner, 2010). The renewability orientation metric, on the other hand, is more concerned with technology implementation. The goal of the renewability orientation metric is to measure the degree to which renewable technologies and services are being actively considered in planning documents.

Percent power from renewables: Most utilities publish their current fuel mix in their Integrated Resource Plans. We took this data and used it as a data point to compare the percentage of renewable-generated power that each utility had integrated into their fuel mix. We were able to find this data for 148 of the 170 electric utilities in our dataset by studying IRPs as well as utility websites and press releases. This metric provided a second firm performance metric as we were able to assess the degree to which each utility had already integrated renewables. Percent power from renewables was thus our second dependent variable.

4.3.3 Inter-Firm Level Factors

Environmental Dynamism: Market turbulence has been positively associated with EO in previous studies but we wanted to see if it was influential in the power industry (Engelen et al., 2015). In the power industry there is a recent trend of deregulation where utilities are able to compete for customers for the first time. We thus characterized deregulated states as high in market dynamism, as distribution utilities need to compete with one another for clients. In regulated states residents have no choice in their distribution utility. This variable thus speaks to the impact of customer choice, as consumers in deregulated states are able to choose their energy provider whereas local monopolies exist in regulated states. In the competitive environment of a deregulated state we predicted that utilities would seek to use renewables as a form of competitive advantage. As a result, we hypothesized that environmental dynamism would be highly correlated with Renewability Orientation and percent power from renewables.

H1a: Market dynamism will make it more likely for utilities to talk about renewables

H1b: Market dynamism will increase the likelihood that a utility sources energy from renewables

Renewable Portfolio Standards: This state-level policy requires utilities to source a certain percentage of their overall fuel mix from renewables. These standards can be required, recommended, or non-existent depending on the state where the utility functions. Previous studies have found that Renewable Portfolio Standards are effective at increasing the percentage of power that a utility derives from solar (Sarzynski et al., 2012). We predicted that Renewable Portfolio Standards (RPS) would similarly be positively correlated to the overall percentage of power that a utility derives from renewables. However, we did not believe that this policy would have a direct impact on renewability orientation.

H2: Renewable Portfolio Standards will increase the likelihood that a utility sources energy from renewables

Rurality: Rurality is important to consider in any study of renewable energy. The promise of renewable energy and the reality of its implementation in rural America today points to potential equity concerns. Previous literature has found that rural states are more likely to derive power from renewables, but that issues like the siting and ownership of infrastructure often lead to conflict and resistance from rural communities (Hyland and Bertsch, 2018; Marsden, 2016; Naumann and Rudolph, 2020). The benefits that renewable deployment could have on rural America are numerous, but recent studies suggest that there are flaws in the existing implementation strategy.

Rural goals such as self-reliance and economic growth could be assisted through the increased penetration of renewables. Research has found that rural communities have higher levels of social cohesion, trust, and embeddedness which make them particularly well positioned to support community renewable energy initiatives and rural social entrepreneurs (Morrison and Ramsey, 2019). Renewable energy also has the potential to support rural identities like self-reliance and independence by creating options for customers to isolate themselves from issues related to the larger grid (Slama, 2004). Further, the development of renewables is often considered a key strategy for helping rural communities enliven job markets (Späth and Rohracher, 2010). While in theory the proliferation of renewables should be welcomed by rural communities, research suggests that the way these projects are implemented undermines the social benefits of renewable deployment.

In practice renewable energy installations are often not delivering on their promise. High numbers of permanent, long term jobs are not usually created when large private corporations install wind turbines in rural areas (Bergmann et al., 2008). Additional research suggests that the economic promise of a more vibrant economy is rarely fulfilled when renewable energy projects are privately owned (Munday et al., 2011). While wind energy is the most likely to create conflict, bioenergy and geothermal have also been problematic (Baumber et al., 2011; Kunze and Hertel, 2017; Naumann and Rudolph, 2020). Rural energy transitions are frequently hotly contested, so we hypothesized that utilities might in rural states might be less inclined to show high levels of support for renewables. In contrast, we also hypothesized that renewables would be more prevalent in rural states and thus rurality would be positively correlated the percent of power from renewables. The goal of this research question was to understand the severity of the rural conflict with the energy system transition.

H3a: Rural communities will be less likely to talk about renewables

H3b: Rural utilities will be more likely to source power from renewables

4.3.4 Firm Level Factors

Entrepreneurial Orientation. We measured each utility's proactiveness, innovativeness, and risk-taking preferences by analyzing the language that utilities included in their IRPs. Previous research has connected entrepreneurial orientation to different expressions of firm performance such as profitability and an increase in sales (Baker and Sinkula, 2009; Covin et al., 2006; Rauch et al., 2009). EO has also been correlated to non-financial performance metrics like forming strategic partnerships, keeping talented employees, increasing employee motivation, and creating a positive culture (Marino et al., 2002; Zahra, 1993) . Researchers in Information Studies have posited that utilities with a culture of innovation will be more likely to be early adopters of renewable energy technologies, although they note that there is limited research to date on technology adoption decisions in regulated industries like the power industry (Dedrick et al., 2015). This research question explores the relationship between entrepreneurial orientation and utility commitment to renewables, hypothesizing that entrepreneurial utilities will be more likely to derive energy from renewables and talk about renewables in their planning documents.

H4a: Entrepreneurial orientation should be associated with a focus on decarbonization in utility planning documents

H4b: Entrepreneurial orientation should be associated with the percent of power from renewables in a utility's fuel mix

Firm Ownership/Size: Certain elements of utility performance, lower costs and higher quality, have been associated with public ownership in previous studies (Kwoka Jr, 2005; Meade and Söderberg, 2020). There has not been any research yet, however, on how utility ownership structure correlates to a utility's commitment to renewables. There are three types of utility ownership structures: IOU's, municipal utilities, and rural electric cooperatives. IOU's are the only ownership type that is privately owned and far larger than the other types of utilities which typically only serve a single town. In 2017, 168 IOU's provided power to 72% of U.S. electricity consumers (Energy Information Administration, 2019). While rural cooperatives are much smaller they actually serviced 56% of the land in the United States in 2019 (NRECA, 2019).

While there is extensive literature on the impact of firm size on entrepreneurial orientation (see (Chen and Hambrick, 1995) or (Wales et al., 2011)), the impact of firm ownership structure has received less attention in the literature. In the energy transition literature there is a large body of literature on the impact of utility ownership structure and firm performance with a focus on the performance metrics of cost and reliability (Carley, 2009; Kwoka Jr, 2005; Meade and Söderberg, 2020). This research seeks to contribute to this ongoing debate by investigating the connection between ownership structures and environmental consciousness. Since privately owned utilities are larger and controlled by board members rather than local residents, we hypothesized that they would be less likely to risk their profits in order to invest in renewables, despite the environmental priorities of their customer base. This prioritization of profits over community goals would manifest as both less power from renewables on average and a lower frequency of language regarding renewables and efficiency in their IRP's.

H5a: Privately owned utilities will be less likely to talk about renewables than publicly owned utilities

H5b: Larger/privately owned firms will be less likely to get power from renewables

Firm Age: We included data on the year in which each utility was founded in order to contribute to the literature on the relationship between firm age and entrepreneurial orientation. Prior research has found that older firms are less likely to convert entrepreneurial orientation into higher performance metrics (Hult et al., 2003; Wales et al., 2011). We predicted that older utilities would be more set in their ways and less inclined to talk about renewables and efficiency in their planning documents. We did not investigate the link between firm age and fuel mix because generation installations in the power industry take an extremely long time to build, so younger firms may not have had sufficient time to signal their environmental consciousness through increasing the percent power from renewables.

H6: Older firms will talk less about renewables

4.3.5 Individual Level Factors

CEO Gender: We believed that female leaders would have a higher renewability orientation and be more likely to source power from renewables. Identity characteristics of CEOs have been found to mitigate the relationship between entrepreneurial orientation and performance in previous studies on family business (Miller and Le Breton–Miller, 2011). Further, research has shown that women are more likely to engage in environmental actions and to invest in renewable technologies (Allison et al., 2019; Zelezny et al., 2000). However, female leadership in the transition from fossil fuels to renewables has not been widely acknowledged or even recognized (Allen et al., 2019). We wanted to see if the gender identity of the utility's manager would impact the firm's renewability orientation. Based on the available literature we hypothesized that utilities managed by females would more likely to source power from renewables and discuss renewables in their planning documents.

H7a: Utilities managed by women will be more likely to talk about renewables

H7b: Utilities managed by women will be more likely to source power from renewables

CEO Tenure: A heightened awareness of institutional norms can create value-laden choices that reflect norms and traditions more directly than immediate market needs (Oliver, 1997). Previous literature has demonstrated that the effect of CEO tenure on entrepreneurial orientation tends to follow an inverted-u shaped curve, and that EO in non-family firms tends to decline much more precipitously after about 15 years of experience (Boling et al., 2016). Based on the nature of this curve and the high average tenure of utility management (mean = 18.2 years), we hypothesized that the length of time a manager worked in the power industry would be inversely related to the firm's positioning towards renewables.

H8a: Managers with more experience in the power industry will be less likely to talk about renewables

H8b: Managers with more experience in the power industry will be less likely to source power from renewables

4.3.6 Moderators

Rurality and Deregulation: In deregulated states, customer preference is likely to have a greater influence on a utility's action. If a utility needs to compete for customers they will pursue strategies designed to appeal to their customers values and priorities. Given the problematic implementation of renewables in rural areas to date as detailed above, we hypothesized that resistance to renewables would be exacerbated in deregulated rural states.

Prior literature has investigated the connection between deregulation and the diversification of fuel mixes in electric utilities and found that deregulation can lead to greater consumer choice, particularly when the population served values renewable energy (Carley, 2009; Delmas et al., 2007). Rural populations, however, often have reason to resist the proliferation of renewables. While some studies provide evidence that dynamism is positively correlated to green innovation (Chan et al., 2016), we believed that the story would be different for electric utilities in rural states. We hypothesized that deregulated rural states would both talk less about renewables in their planning documents and be less likely to source power from renewables.

H9a: Utilities in deregulated states with rural populations will be less likely to signal environmental consciousness in their planning documents.

H9b: Utilities in deregulated states with rural populations will be less likely to source energy from renewables.

Rurality and Entrepreneurial Orientation: Entrepreneurial orientation has been associated with firm performance repeatedly in the literature and so we had reason to believe that it would also be correlated to our non-financial performance measures related to renewability (Linton and Kask, 2017). If a firm is innovating and leaning into the energy system transition, then the availability of land should make it easier for them to execute on their goals. In a culture of proactiveness, innovation, and risk taking we would expect to provide support for theoretical studies claiming that innovation in the power industry is correlated to investment in renewable technology (Dedrick et al., 2015). We felt that this relationship would be particularly strong in rural states in light of the availability of undeveloped land and previous studies that have found that renewables are more likely to be sited in rural areas (Marsden, 2016). We thus hypothesized that rurality would amplify the relationship between entrepreneurial orientation and environmental consciousness.

H10a: Entrepreneurial orientation will have a stronger relationship on renewability orientation in rural states.

H10b: Entrepreneurial orientation will have a stronger relationship to percent power from renewables in rural states.

4.3.7 Simultaneous Equation Estimation

The literature has established that there are multiple institutional factors that influence a firm's strategic orientation (Ang et al., 2015; Engelen et al., 2015). In the context of the power industry, utility's renewability orientation may influence the utility's percent generation from renewables (fuel supply mix). Simultaneously, the percentage of renewables in a utility's fuel mix may influence their renewability orientation. This relationship violates the assumption of strict exogeneity and requires appropriate statistical methods. The use of simultaneous regression models are required to accommodate the violation of this assumption (Maddala and Lahiri, 2009). We use two-stage least squares to test for simultaneity of the two dependent variables.

We hypothesized that firms that talked more about renewables (RO) would have more renewables (PfR). Rationally it would make sense that an orientation towards renewables would result in more renewables. However, energy infrastructure is expensive and takes a long time to build. Our results did not find evidence of this relationship which could be, at least in part, attributed to a significant time lag between the decision to invest in renewables and ultimately deriving power from them. The second dimension of this hypothesis is that firms with more renewables in their portfolio would talk more about renewables. In other words, if a utility is walking the walk then they will also talk the talk. This was a negative relationship which is interesting and worthy of deeper investigation.

H11: Both Renewability orientation and percent power from renewables are dependent on one another.

4.4 Methodology

4.4.1 Sample

A total of 170 electric utilities were selected for this analysis. These utilities were selected after a national search for utility Integrated Rate Plans (IRP's). Only electric distribution utilities were chosen, excluding utilities that only provide transmission and generation to utilities and did not directly distribute power to end clients. Integrated Rate Plans are only required in certain states, so the selection was limited to utilities in states that require IRP's. Further, some state regulations only require Investor-Owned Utilities (IOU's) to publish Integrated Rate Plans. As a result, certain states only had IRP's from Investor-Owned Utilities. The data collection effort thus included all of the electric utilities in the United States where IRP's were found.

IRP's were selected as the key criteria for inclusion because they provide a unique and powerful level of insight into electric utility planning processes. IRP's include input assumptions for demand and supply for each utility, including the energy generation resources they currently hold and those they intend to build (Wright et al., 2017). These documents go into detail on their strategic plans to implement energy efficiency programming and invest in renewable generation. The lengths of the documents varied widely, with the word count ranging from 452 words to 170,431 and a mean of 20,319 words. They were published by all types of utilities across thirty states (see Table 4.1). By including all available IRPs in this analysis we were able to control against selection bias.

Table 4.1. Utility Characteristics.

Type of Utility	Count
Investor-Owned Utility	70
Municipal Utility	67
Rural Electric Coop	17
Other (CCA, ESP, and PUD)	16

4.4.2 Measures and Data Analysis

We developed the two dependent variables, renewability orientation and percent power from renewables, and the independent variable of entrepreneurial orientation by analyzing the language and content of these IRPs. Consistent with the procedure outlined by (McKenny et al., 2016) and implemented by various EO researchers (Covin and Wales, 2012; Wales, 2016). A computer-aided text analysis was employed to assess the entrepreneurial orientation of each of the utilities in the data set using their IRPs. Each Integrated Resource Plan was scored for innovativeness, proactiveness, and risk taking (Linton and Kask, 2017; Rauch et al., 2009) and then normalized by word count. This yielded an EO score for each utility. The IRP's were then run through a new dictionary we created which we named Renewability Orientation. This list of efficiency and renewable terms was matched to each utility IRP in order to measure the relative degree of focus on energy efficiency and renewable integration for each utility in our data set. We also analyzed the content of the Integrated Resource Plans in order to find the current percent of renewables in the utility's power supply mix, supplementing this dataset with data from utility websites and press releases when it was not available in the IRP. It was not possible to find fuel mix data for every utility and the final data set included fuel mix data for 148 of the 170 electric utilities in the study. Measurement error is a concern but it was addressed by manually coding each of the IRP's in order to ensure that the word counts were accurate in addition to managing transient error by controlling for the year in which the IRP was published (McKenny et al., 2016). We also took a proactive approach to managing specific factor error in creating the new Renewability Orientation metric because the energy transition context of electric utilities required industry-specific terminology.

Independent variables were continuous, binary, or categorical (recoded into binary dummy variables). At the inter-firm level, rurality was a continuous variable obtained from the most recent report by the United States Census Bureau (United States Census Bureau, 2010). Dynamism was a binary variable denoting whether or not a state was deregulated or not based on data from Electric Choice (Electric Choice, 2018). Data on state Renewable Portfolio Standards was categorical, as states could have no RPS requirements, RPS goals, or RPS standards as reported in the DSIRE database (NC Clean Energy Technology Center, 2018). At the firm level, entrepreneurial orientation was a continuous variable that we built internally based on the most recent entrepreneurial orientation CAT scanner word list designed for the literature on Management & Entrepreneurship to assess innovativeness, proactiveness, and risk-taking (McKenny et al., 2018). The independent variable representing ownership structure was constructed using dummy variables for the three main ownership types that we wanted to compare: Investor-Owned utilities, Municipal Utilities, and Rural Electric Cooperatives based on data from the Energy Information Administration (EIA, 2017). There was very high collinearity between firm ownership structure and firm size. IOU's were the largest with an average of 711,149 customers, Municipal utilities were mid-sized with an average of 142,892 customers, and rural coops were much smaller with an average customer base of 26,539. We decided to focus on firm ownership instead of firm size for this analysis because of the ongoing debate in the power industry around the comparative advantages of private ownership structure (for example, see (Penn, 2019)). Firm age and gender of the General Manager were assessed by visiting each utility's website. Firm age was recorded as the year that the utility was established and thus was represented in the data set as a continuous variable. At the individual level, gender was a binary variable and industry experience was a continuous variable.

Our two dependent variables, percent power from renewables and RO, did not follow a normal distribution ($p<.0005$ in the Shapiro-Wilk W test). We determined that percent power from renewables followed an exponential distribution by applying the Kolmogorov's D test for goodness of fit where Prob>D = .1500. Since the p value was not less than .05 we accepted the null hypothesis that this variable followed an exponential distribution. Renewability Orientation followed a Johnson SI distribution which we confirmed using a Shapiro-Wilk W test where Prob<W = .1023, enabling us to accept the null hypothesis that the variable follows a Johnson SI distribution. We believed that there would be a relationship between discussing renewables in planning documents (RO) and deriving power from renewables (percent power from renewables), so we chose to use simultaneous equation estimation. Since our data was finite and unbiased the results were also of finite variance and unbiased, so using ordinary least squares as part of our simultaneous equation estimation did not compromise the validity of our model (Tellinghuisen, 2008).

This study used ten total variables, based on theories from the energy system transition literature and resource-based institutional theory (see Figures 4.2 and 4.3). We applied Oliver's framework to construct our analysis, first assessing the impact of the independent variables at each of the three levels on the dependent variables of renewability orientation and percent power from renewables for each utility. Model 1 included factors at the inter-firm level, model 2 included factors at the firm level, and model 3 included factors at the individual management level. Model 4 included variables at all three levels, and our final model included interaction effects. We used different selections of variables for each of the two dependent variables (see Tables 4.2 and 4.3).

Table 4.2. Independent variables for renewability orientation.

Variable	Expected Sign	Theory	Literature
Dynamism	Positive	Dynamism will encourage more innovative behavior	Engelen, 2015
Rurality	Negative	Rural residents will resist land use for renewables	Hyland & Bertsch, 2018
Ownership Type	Positive	Private utilities are more likely to have distributed generation	Kwoka, 2005
FirmAge	Negative	Older companies are less able to convert EO into firm performance	Wales, Monsen, & McKelvie, 2011; Hult, 2003
Entrepreneurial Orientation	Positive	EO will be correlated to firm performance	Anderson & Eshima, 2013; Linton & Kask, 2017
Gender of CEO	Positive	Women invest more in renewables	Allison, 2019; Zelezny, Chua, & Aldrich, 2000
CEO Tenure	Negative	Higher isomorphism	Boling, Pieper, & Covin, 2016

Table 4.3. Independent variables for percent power from renewables.

Variable	Expected Sign	Theory	Literature
Dynamism	Positive	Dynamism will encourage more innovative behavior	Engelen, 2015
RPS	Positive	RPS will encourage adoption of renewables	Sarzynski, Larrieu, & Shrimali, 2012
Rurality	Positive	Rural states will have more land available for renewables	Bergmann, Colombo, & Hanley, 2008
Ownership Type	Negative	Large private firms will have a smaller percentage of renewables	Hult, 2003, Meade & Söderberg, 2020
Entrepreneurial Orientation	Positive	EO will be correlated to firm performance	Anderson & Eshima, 2013; Linton & Kask, 2017
Gender of CEO	Positive	Women invest more in renewables	Allison, 2019; Zelezny, Chua, & Aldrich, 2000
CEO Tenure	Negative	Higher isomorphism	Boling, Pieper, & Covin, 2016

Table 4.4. Descriptive statistics.

Variable	Mean	SD	Min	Max
Renewability Orientation	0.066	0.06	0	0.47
Percent Power from Renewables	0.311	0.274	0	1
Dynamism	0.341	0.476	0	1
Rurality	25.382	18.826	6.33	66.96
RPS	1.476	0.793	0	2
IOU	0.414	0.494	0	1
Muni	0.396	0.491	0	1
Entrepreneurial Orientation	0.063	0.043	0.006	0.395
FirmAge	86.144	39.903	0	139
CEO Gender	0.168	0.375	0	1
CEO Tenure	18.2	11.02	1	41

We further established that the independent variables were not colinear (see Figure 4.8). The variance inflation factors were all smaller than 3, significantly less than the hold criterion of 10, indicating that our results were unlikely to have been influenced by multicollinearity (Brettel et al., 2010; Engelen et al., 2015).

Table 4.5. Correlation Table.

Variable	1	2	3	4	5	6	7	8	9	10	11
1. Renewability Orientation	1.0000										
2. % Power from Renewables	0.1799	1.0000									
3. Market Dynamism	0.1627	0.3706	1.0000								
4. Rurality	-0.2015	-0.0279	-0.4564	1.0000							
5. RPS	-0.0204	0.4112	0.4135	-0.1362	1.0000						
6. IOU	-0.1173	-0.3950	-0.0409	0.1255	-0.1840	1.0000					
7. Muni	-0.0355	0.2491	-0.0665	-0.0063	0.1417	-0.6815	1.0000				
8. Entrepreneurial Orientation	0.2920	0.1788	0.1542	-0.2019	0.0700	-0.1405	-0.0865	1.0000			
9. Firm Age	0.2765	0.0317	0.1335	-0.2356	0.1168	-0.2315	-0.1447	0.2572	1.0000		

10. CEO Gender	-0.0644	0.0934	0.0160	0.1923	0.0332	0.0087	-0.0699	0.0162	-0.0747	1.0000	
11. CEO Tenure	-0.0311	-0.1531	-0.0882	-0.0844	-0.2149	-0.1177	0.0483	0.0450	0.1437	-0.0470	1.0000

4.5 Results

4.5.1 Main Effects: Renewability Orientation H1a – H10a

We built six models to explain the variability in renewability orientation across electric distribution utilities. Based on Oliver's framework we measured the impact of independent variables at each three levels on RO. The first model looked at the impact of these inter-firm variables on RO: market dynamism (deregulation of the energy marketplace) and percent rurality in the state. The second model looked at the impact of ownership type and EO score on RO, and the third model looked at the impact of the gender of the firm manager on RO. The fourth model included variables at all three levels and the final model included interaction effects. Our final model, Model 6, assesses the relationship between the two dependent variables via simultaneous equation estimation. Firm age is the identifying variable. We report results using a standardized beta in order to compare the variables to one another more easily.

Results of Multiple Linear Regression for Renewability Orientation (H1a - H10a)																		
	Model 1			*Model 2*			*Model 3*			*Model 4*			*Model 5*			*Model 6*		
	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***
Intercept	0	0.013	****	0.000	0.017	**	0.000	0.011	****	0.000	0.022	***	0.000	0.021	***	0.000	0.03	****
Independent Variables																		
Inter-Firm Level																		
Dynamism	0.07	0.013								0.031	0.011		-0.078	0.012		0.151	0.017	
~~RPS~~																		
Rurality	-0.167	0	*							-0.117	0.000		-0.230	0	***	-0.210	0	***
Firm Level																		
IOU				0.008	0.014					-0.006	0.014		0.081	0.014		-0.225	0.021	
Muni				0.100	0.014					0.065	0.014		0.067	0.014		0.078	0.014	
EO				0.541	0.146	****				0.543	0.144	****	0.550	0.144	****	0.769	0.226	****
Firm Age				-0.261	0.000	***				-0.256	0.000	***	-0.256	0	***	-0.257	0	****
Individual Level																		
CEO Gender							-0.070	0.011		-0.088	0.012		-0.107	0.012		-0.073	0.012	
CEO Tenure							-0.035	0.001		-0.119	0.000		-0.117	0	*	-0.298	0	***
Interaction Terms																		
Rurality * EO													-0.106	0.001		-0.034	0.012	
Rurality * Dynamism													-0.209	0.001	**	-0.668	0.002	***
Simultaneous Equation Estimation																		
Predicted Percent Power from Renewables																-0.782	0.096	**

Model Fit						
	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
N	128	128	128	128	128	128
R^2	0.044	0.385	0.006	0.423	0.466	0.493
Adj R^2	0.029	0.365	-0.01	0.385	0.420	0.445
Prob > F	p = .0588	p < .0001	p = 0.6901	p < .0001	p<.0001	p<.0001

*Notes: IOU and Muni are dummy variables and are compared to rural cooperatives. * p<.1. ** p<.05. ***p<.01. ****p<.001. N=128.*
Firm Age is the identifying variable for the simultaneous equation estimation.

Figure 4.2. Results of the multi-regression analysis with renewability orientation (RO) as the dependent variable.

Firm level variables appeared to explain the majority of the variation in utility RO. In particular, entrepreneurial orientation was highly correlated to RO which supported our hypothesis that entrepreneurial orientation would be correlated to this non-financial metric of firm performance. Utility ownership structure did not significantly alter utility positioning towards renewables, a finding that caused us to reject our hypothesis that publicly owned utilities would position themselves more aggressively towards a future powered by renewables. A key finding here was the importance of

Oliver's tiered perspective. While there was significance in the model that used only variables at the firm level, the model became much stronger when variables at all three levels were allowed to interact with one another. Including the simultaneous equation estimation in order to incorporate percent power from renewables improved the model by 2.7% and the additional term was significant and negative.

Hypothesis testing for the effect of rurality as a moderator of renewability orientation followed the protocol implemented by Anderson et al. (2009) and mapped out by Baron and Kenny (1986). We wanted to understand how the moderator, rurality, changed the effect of the independent variables, deregulation and EO, on the dependent variable RO. We hypothesized that the effect would be a gradual, steady change as the moderator changes, the most frequently assumed relationship between variables (Baron and Kenny, 1986). These results caused us to reject our hypothesis that entrepreneurially oriented utilities in rural states would be more likely to discuss renewables. Rurality did, however, strengthen the negative relationship between market dynamism and renewability orientation. When the marketplace is open to competition utilities in rural states are even less likely to discuss renewables and efficiency. This negative relationship supports the hypothesis that market preferences in rural states run contrary to policy goals for decarbonizing the grid.

4.5.2 Main Effects: Power from Renewables H1b – H10b

This analysis was implemented in a similar fashion to the models above, although the variables included were not identical. At the inter-firm level (Model 1) we looked at the impact of market dynamism, renewable portfolio standards (RPS), and the rurality of the state's population to explain the variability in utility power supply. At the firm level we tested the effects of utility ownership structure and entrepreneurial orientation on the percent power from renewables (Model 2). At the individual level we investigated the impact of the manager's gender on the dependent variable (Model 3). Model 4 included variables at all three levels and Model 5 included interaction effects. Model 6 is the simultaneous equation estimation, and the identifying variable is Renewable Portfolio Standards (RPS).

Results of Multiple Linear Regression for Percent Power from Renewables (Hb - H10b)

	Model 1			*Model 2*			*Model 3*			*Model 4*			*Model 5*			*Model 6*		
	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***	β	S.E.	***p***
Intercept	0	0.061		0.000	0.077	****	0.000	0.050	****	0.131	0.098		0.000	0.09	*	0.000	0.107	
Independent Variables																		
Inter-Firm Level																		
Dynamism	0.336	0.058	****							0.337	0.052	****	0.160	0.052	*	0.159	0.052	*
Rurality	0.123	0.001								0.178	0.001	**	0.021	0.001		-0.027	0.002	
RPS	0.295	0.031	***							0.222	0.029	***	0.153	0.026	**	0.127	0.029	
Firm Level																		
IOU				-0.389	0.065	***				-0.384	0.057	****	-0.270	0.054	***	-0.284	0.054	***
Muni				-0.003	0.069					-0.008	0.059		0.015	0.054		0.000	0.055	
EO				0.163	0.738	*				0.153	0.637	**	0.207	0.595	**	0.320	1.303	**
~~Firm Age~~																		
Individual Level																		
CEO Gender							0.111	0.064		0.055	0.052		0.028	0.048		0.002	0.053	
CEO Tenure							-0.148	0.002	*	-0.127	0.002	*	-0.145	0.002	**	-0.166	0.002	**
Interaction Terms																		
Rurality * EO													0.057	0.041		0.031	0.045	
Rurality * Dynamism													-0.401	0.003	****	-0.446	0.004	****
Simultaneous Equation Estimation																		
Predicted Renewability Orientation																-0.145	1.051	

Model Fit

	Model 1	*Model 2*	*Model 3*	*Model 4*	*Model 5*	*Model 6*
N	128	128	128	128	128	128
R^2	0.256	0.188	0.036	0.429	0.533	0.536
Adj R^2	0.238	0.168	0.02	0.390	0.493	0.492
Prob > F	p<.0001	p<.0001	p=.1026	p<.0001	p<.0001	p<.0001

*Notes: IOU and Muni are dummy variables and are compared to rural cooperatives. * p<.1. ** p<.05. ***p<.01. ****p<.001. N = 128. Renewable Portfolio Standards (RPS) are the identifying variable for the simultaneous equation estimation.*

Figure 4.3. Results of the multi-regression analysis with percent power from renewables as the dependent variable.

In this analysis inter-firm level variables were much more relevant than in the analysis of renewability orientation. Deregulation, rurality, and the existence of renewable portfolio standards at the inter-firm level all made it more likely for a utility to derive power from renewables. Utility ownership structure predicted more variability in this model as well. Investor-owned utilities were significantly less likely to derive power from renewables than municipal or rural utilities. As Oliver predicted, the model became much stronger when variables across all levels were able to interact in Model 4. Model 5 was the strongest, however, suggesting that the rurality of a state has a significant impact on a utility's likelihood of deriving power from renewables. The inclusion of RO through the simultaneous equation estimation only explained 0.3% more variability and the new term was not significant, indicating that the amount of language a utility uses regarding renewables and efficiency is not significantly correlated to how much power they derive from renewables.

Rurality strengthened the effects of both entrepreneurial orientation and deregulation on percent power from renewables. Taken alone as an independent variable, rural states were more likely to derive power from renewables as we had hypothesized. Furthermore, utilities with an entrepreneurial mindset were even more likely to derive power from renewables if they lived in rural states. However, utilities in deregulated states were much less likely to derive power from renewables. This finding pointed to a strong interaction effect between rurality and deregulation that was similar to that uncovered in the RO analysis: rural utilities that need to compete for customers once again appear to be addressing customer preferences that run counter to policy priorities for a decarbonized grid.

4.5.3 Simultaneous Equation Estimation

Given the clear connection between talking about renewables and efficiency in planning documents and deriving power from renewables, we hypothesized that there would be a connection between our two dependent variables. In order to understand how renewability orientation was related to percent power from renewables we used simultaneous equation estimation. The structural equations are written as follows:

$$\% \, Power \, from \, Renewables = \widehat{RO} + \alpha_1 Dynamism + \alpha_2 Rurality + \alpha_3 \, RPS + \alpha_4 IOU + \alpha_5 Muni + \alpha_6 EO + \alpha_7 \, CEOGender + \alpha_8 CEOTenure \quad (1)$$

$$Renewability \, Orientation = \% \, Power \, \widehat{from} \, Renewables + \alpha_1 EO + \alpha_2 Firm \, Age + \alpha_3 \, \% \, Pop \, Rural + \alpha_4 IOU + \alpha_5 Muni + \alpha_6 Deregulated + \alpha_7 \, CEOGender \quad (2)$$

We used a simultaneous equation model because we believed that the dependent variable Renewability Orientation would affect the dependent variable Percent Renewable. When a dependent variable is determined by both independent and dependent variables, the parameter identification problem can occur. An accepted method for addressing this problem is to satisfy the rank and order conditions using a two stage least squares methodology as we did here (Fisher, 1966). Since our linear system included two equations we needed to exclude one variable for each equation. To identify the RO function the identifying variable was FirmAge and to identify the Percent Renewable function the identifying variable was RPS. This satisfied the rank and order conditions.

Our simultaneous equation estimation revealed that there was no significant relationship between Renewability Orientation and actually deriving power from renewables (Percent

Power from Renewables). In other words, talking about renewables did not predict an increased likelihood to derive power from renewable energy.

There was significance in the model predicting renewability orientation, however, but in a direction counter to our hypothesis. Our simultaneous equation estimation predicts that firms that talk more about renewables are significantly less likely to derive power from renewables. This could be due to time lags between planning and implementation or a reflection of increased efforts by firms lagging behind in the converting their generation to renewables.

4.6 Discussion

Our study offers multiple contributions to the literature. We extend the study of entrepreneurial orientation to a regulated industry, apply Oliver's resource-based institutional theory to the power industry while shedding light on ongoing debates in the energy transition literature. Each of these contributions is addressed separately below.

4.6.1 Contributions to Resource-Based Institutional Theory

This research fills a gap in the literature on resource-based institutional theory in entrepreneurship research. A recent literature review noted an alarming lack of meso-level studies at the industry level, noting that most research is concerned with the national level or the individual/organizational level (Su et al., 2017). By including all electric distribution utilities across the United States which filed an IRP, this study leverages a data set that provides a true meso-level perspective on drivers of firm heterogeneity. We use this data set to explain variation in firm performance using Christine Oliver's resource-based institutional theory.

Oliver (1997) created a powerful framework for organizing different drivers of firm heterogeneity. She suggested that factors at the inter-firm, firm, and individual level were all critical to understanding differences between firms, as were the interactions between factors at all three levels. We applied this theory to investigate the drivers of environmental consciousness in United States electric distribution utilities. Our results indicated that our ability to predict variation in firm performance was strengthened considerably by using factors at the inter-firm, firm, and individual levels. In the analysis of RO firm level factors were the most predictors of RO (38.5%) whereas inter-firm (25.6%) and firm level (18.8%) factors were the primary predictors of percent power from renewables. However, allowing for interaction effects and the inclusion of variables at multiple levels resulted in the most robust models.

At the inter-firm level, policies and demographic information had a significant effect on a utility's environmental signaling. Deregulation appeared to be a powerful lever to increase the penetration of renewables in utility fuel mixes, as did Renewable Portfolio Standards. Rurality was also influential but in a more complex way. Rural utilities use more renewable energy than their more urban counterparts but talk about it less. Further, there is a strong interaction effect between deregulation and rurality, demonstrating a very different trend emerging for utilities in rural states where utilities can compete for business. When local constituents can express market preferences in this scenario, they appear to actively resist renewable energy. Where rurality and market dynamism are both positively and significantly correlated to percent power from renewables, the interaction effect of these two variables turns the sign to negative. This interaction effect suggests that the way in which energy generation infrastructure is being rolled out in rural communities is problematic and potentially adversely effecting rural communities.

The significance of these results points to a real area of concern in the energy system transition. If rural electrification is already greeted by local resistance, how will our country meet the ambitious goals set by state and federal governments without exacerbating pre-existing social justice issues in rural America? Rural communities have some of the highest energy burdens in the country given aging building stock, inefficient oil-based heating systems, long commuting distances, and chronic rural poverty. In Vermont – the most rural state in the country by census definition – an average rural, low-income household can spend up to a fifth of their income on energy, distributed across transportation (45%), thermal (35%), and electricity demands (20%) (Sears and Lucci, 2019). The price of power is clearly a concern to rural residents, yet this study reveals that rural consumers do not appear to want their utilities to provide them with renewable energy. Clearly, the financial needs of these customer are not being met through the existing renewable deployment strategy and concerns over siting and community engagement are widespread (Naumann and Rudolph, 2020). These results expose a potential risk that the transition to renewables could be developing in a way that harms vulnerable rural populations.

At the firm level, utility ownership structure, firm age and entrepreneurial orientation were significantly correlated to the environmental signaling of utilities. In fact, firm level factors alone were important enough to build significant models for both of our dependent variables. These models underscored the importance of understanding firm characteristics to predict environmental signaling.

The individual level of analysis was also important, echoing the findings of Finklestein (2004) and Hambrick (1991). While gender did not emerge as a significant variable, more data on female utilities could have strengthened the effect and provided a better test of the theories espoused by researchers who focus on gender and energy (Allen et al., 2019; Pearl-Martinez and Stephens, 2016). CEO tenure did appear to significantly impact the percentage of power from renewables, supporting research on the effect of CEO tenure on willingness to innovate (Boling et al., 2016).

The interaction effect between EO and rurality did not emerge as we had hypothesized. We had anticipated the entrepreneurial utilities in more rural states would move more aggressively to build their renewable energy portfolios. Entrepreneurial orientation was positively correlated to both renewability orientation and to percent power from renewables and we expected the effect to be particularly strong when these two factors overlapped. Our results did not indicate that more entrepreneurial firms in rural areas would be particularly aggressive in their environmental signaling. This suggests that the negative associations that renewable energy has for rural areas may outweigh a utility's desire to be innovative and proactive.

The three levels of analysis played different roles in predicting RO and percent power from renewables. This research demonstrates that inter-firm level factors can be very impactful but regulators need to be wary of interaction effects. Further research could expand upon these initial efforts to include many more inter-firm level independent variables such as additional policies, AMI diffusion, and demographic characteristics. At the firm level it was clear that utility structure does make a difference, and that utilities that adopt a more entrepreneurial stance in their IRP's do indeed lean more aggressively into the energy transition. At the individual level we did not have enough utilities with female entrepreneurs to achieve significance but there was a clear relationship between how long a CEO has been in the utility industry and how entrepreneurial they are willing to be, findings that echo other studies on the relationship between CEO tenure and EO.

Oliver's framework was an effective tool for organizing and understanding how environmental and internal factors can influence firm heterogeneity. We tested hypotheses related to each level in order to confirm Oliver's claim that data from the individual, firm, and inter-firm levels was key for obtaining a clear picture of firm differentiation. Our results clearly indicated that factors across all levels contributed to utility environmental signaling.

4.6.2 Contributions to Management Research

Our results contribute to the existing management literature in several ways. Previous studies have investigated the barriers that sustainable entrepreneurs in the clean energy sector need to overcome in order to be successful, approaching the barriers to innovation from a more exploratory perspective (Pinkse and Groot, 2015). This research takes a more iterative, results-based approach by investigating which institutional contexts are most highly associated with progressive utilities. In the power industry, electric utilities are the gatekeepers to new innovation and sustainable entrepreneurs often must engage with them in order to test their innovations on the grid. By investigating the internal and external factors that impact the renewability orientation of a utility, favorable conditions for sustainable entrepreneurs can be identified and replicated.

An additional contribution is broadening the reach of entrepreneurial orientation research to include regulated industries. The majority of studies on entrepreneurial orientation are conducted based on data from private organizations where firms have the ability to manipulate prices and can grow and scale the products or services they provide. The power industry is fundamentally different because of state regulations, and firm performance in distribution utilities is not expressed through variables like firm age, size, and profitability. This study finds that entrepreneurial orientation is positively associated with firm performance in the regulated power industry, specifically with regards to a utility's commitment to the energy system transition. This suggests that the study of entrepreneurial orientation can be useful in studying drivers of environmental consciousness in the regulated industries.

In addition, this research proposes a new variable for assessing firm performance in the power industry. Renewability orientation is implemented as a novel solution for measuring the frequency of language about renewables and efficiency that occur in utility planning documents. Following the same logic underlying the metric for entrepreneurial orientation, distribution utilities that spent a higher percentage of their IRP word count discussing renewable energy technologies and efficiency strategies are positioning themselves as more committed to the transition to renewables. This new rating system could be used to compare and contrast individual organization's commitment to climate change mitigation in other regulated public utilities such as water or transportation.

These results also speak to the effect of utility size and structure on renewability orientation. Large, privately owned utilities were significantly less likely to derive power from renewables. Previous studies have found that privately owned utilities are more likely to have distributed generation, but also finds that fossil fuels are most prevalent fuel for distributed generation infrastructure (Kwoka Jr, 2005). This research build on the work of Kwoka (2005) confirming that privately owned utilities are actually less likely to source power from renewables. As conversations over energy justice and energy democracy become increasingly prevalent in the energy transitions literature, the opportunities that cooperative ownership structures can provide for community engagement are entering the public narrative. Recently California Mayors submitted a petition to turn Pacific Gas & Electric, one of the largest investor owned utilities the country, into a cooperative utility (Penn, 2019). These results suggest that cooperative ownership structures could increase the likelihood of a firm deriving energy from renewables.

This study also supported key findings that have been uncovered in the literature on the effect of firm age on entrepreneurial orientation. This research showed that older firms were less likely to talk about renewables and efficiency in their IRP's as compared to newer utilities, supporting existing research on the mitigating impact of firm age on ability of a firm to convert entrepreneurial orientation into firm performance (Anderson and Eshima, 2013). Younger firms appear to be leaning into the transition to renewables more aggressively, a finding that echoes the work of other researchers who have reported "learning impediments" in older firms which make it difficult for them to adapt to new challenges (Autio et al., 2000). This study furthers the work of these researchers by measuring this effect in a regulated industry and connecting it with a non-financial performance outcome.

The significance of firm age in predicting a utility's likelihood of deriving power from renewables offers additional support to existing studies on the effect of CEO tenure on firm performance and willingness to innovate. As anticipated, CEO tenure had a significantly negative impact on percent power from renewables. The average tenure of CEO's in our data set was 20 years, five years beyond the mid-point suggested by Boling et al (2016). Therefore over half of our data set should be on a trend line of declining entrepreneurial orientation. A CEO's extended exposure to industry norms and selection of enduring paradigms earlier in their careers appears to limit their willingness to lean into the energy system transition (Hambrick and Fukutomi, 1991). These results support the hypothesis that CEO tenure is significantly related to innovation in the power sector, suggesting that younger, less experienced top management might be a key to expediting the energy system transition.

This work also points to the utility of the CATA analysis strategy to develop best practices for states and regulators as they consider how best to expedite the transition to renewable energy. The effectiveness of policy decisions like passing renewable portfolio standards or deregulating a state can be assessed based on their ability to influence utility thought and action. The relationship between renewable portfolio standards and a relatively higher percentage of renewables in a utility fuel mix echoes the findings of other researchers and provides quantitative evidence to support enacting renewable portfolio standards (Anguelov and Dooley, 2019). Deregulation, on the other hand, is a bit more complex. While distribution utilities in deregulated states are more likely to source power from renewables this relationship does not hold true in rural states. A potential conclusion for policy makers interested in catalyzing the energy system transition would be to strongly support renewable portfolio standards but approach deregulation with caution.

4.6.2.1 *The Double-Edged Sword of Deregulation*

The global trend of electricity deregulation is fundamentally changing electricity marketplaces. In deregulated regions, consumers have the right to buy their power from a Retail Electric Providers (REP). REPs compete with utilities through lower prices, cleaner energy, and creative billing strategies. They purchase power on the wholesale market and leverage the utility's transmission and distribution system to bring that power to consumers. Should a consumer choose to work with a REP their bill will have two components: roughly half will pay for infrastructure costs related to distribution and transmission while the second half will go directly to the REP (Electric Choice, 2020).

The push for deregulation stems in large part from consumer frustration with the pace of change in the power industry. Utilities are notoriously risk averse with little financial incentive to innovate and lean into radical change. A primary argument for creating a competitive electric market was the potential to lower costs and lower prices for consumers (Dooley, 1998). Analysis of deregulated marketplaces have backed up this claim, observing improvements in efficiency and productivity among utilities in a deregulated marketplace (Goto et al., 2013; Wang and Mogi, 2017). Deregulation was further expected to drive radical innovation in the power industry as market preferences for renewables would be expressed in a competitive marketplace (Markard and Truffer, 2006; Zame et al., 2018). Research has not supported the fulfillment of this objective, however, as R&D efforts in deregulated marketplaces tend to become explicitly tied to business needs rather than policy considerations (Dooley, 1998).

In this analysis we analyzed the impact of deregulation (market dynamism) on utility fuel supply mix and renewability orientation. When the effect of dynamism is isolated in our Percent Power from Renewables model it is very negative (-47), indicating that dynamism is associated with a much lower percentage of power from renewables. In our analysis of renewability orientation the impact of deregulation is only slightly positive. These results would suggest that utilities in deregulated market environments talk slightly more about renewables but use far less of them in their fuel mix.

A possible explanation for this finding is the fact that electric utilities are natural monopolies (Jamasb and Pollitt, 2008). Electric utilities have high fixed costs and low marginal costs and as such they should be public or regulated in order to maximize economic efficiency (Farley et al., 2015). In monopolies it does not make sense for fixed costs to be duplicated and cooperation is critical to maximizing market efficiency. There are risks to creating competitive marketplaces for natural monopolies. Since electricity is a basic need and highly price inelastic, small changes in the supply or demand of power can result in enormous changes in price that are reminiscent of what happened in California in 2001 (Farley et al., 2015). Without regulation, speculators can enter the marketplace and manipulate supply in order to increase prices. Regulation or public ownership is a way to insulate consumers from this type of risk.

The diffusion of renewable energy is exacerbating the monopolistic nature of the industry, as wind and solar have very high fixed costs but no marginal costs aside from infrastructure maintenance. During times of high output when the sun is shining and the wind is blowing, energy is almost non-rival as abundant inexpensive energy is produced that cannot be affordably stored. A profit-maximizing utility would seek to limit output in order to maximize profit. In order to maximize the economic surplus, however, the price would need to trend towards marginal costs, which are often negligible (Farley et al., 2015). This would suggest that an electric utility that was providing least cost power to customers and investing aggressively in renewables should actually be losing money in order to maximize contribution to the public good.

There is considerable research on innovation in natural monopolies. Schumpeter proposes that large monopolies are capable of the most rigorous innovation because they have a steady flow of cash to invest in research and they are insulated from market pressures (Schumpeter, 2013). In practice, however, electric utilities often demonstrate strong path lock-in (Markard and Truffer, 2006). Research on innovation in the deregulated Japanese electric sector offers a more nuanced perspective of how innovation is manifested amongst competitive energy suppliers in practice. Wang and Mogi (2017) found that patents increased as utilities became increasingly concerned with protecting their innovations from their competitors. While this outward increase in innovative activity may seem promising at first glance, the containment of promising new technologies and best practices through the patent process is the opposite of what should be encouraged in a natural monopoly where everyone benefits from a decarbonized, more efficient electric grid. There is also a shift towards more short-term R&D in deregulated marketplaces (Dooley, 1998). Studies have found that long term research related to new ways of envisioning the grid or developing early stage technologies are taking a back seat to innovations pertaining to short-term cost reduction strategies (Dooley, 1998; Wang and

Mogi, 2017). Innovation is thus accelerating according to metrics like patent filings but long term research into clean technologies is decreasing in deregulated marketplaces (Dooley, 1998).

There are potential pathways for alleviating some of these issues. Mandated open access to new technologies could drive more long term innovation research and ensure that energy suppliers aren't duplicating their R&D efforts (Farley et al., 2015). Government funding of R&D could further promote and support research on renewables and clean technology (Wang and Mogi, 2017). Additional research on strategies that other countries have employed to bolster renewable energy research would shed light on options for moving forward.

Deregulation appears to be a double-edged sword. Risk averse utilities were not moving quickly enough to transition to renewables or investing aggressively enough in innovations to cut costs. Deregulation succeeded in putting new pressure on utilities and giving the consumer marketplace a means to express their preferences. However, in a monopolistic industry like the power industry, cooperation is critical for achieving environmental and economic goals. In a marketplace where revenue is uncertain and green technology is hoarded to maximize profits, there is reason to fear that innovation may become a more individualistic imperative concerned with the survival of the fittest, not the survival of the group.

4.7 Research Limitations and Future Directions

These results were limited by the availability of data. Only 33 states require distribution utilities to publish integrated resource plans, and some of those states only require Investor Owned utilities to publish these reports (American Wind Energy Association, 2020). The data set would have been stronger if more utilities were required to publish integrated resource plans. It was also difficult to find current data on utility fuel mixes, as this data point often did not exist or was buried in the IRP. It would have been interesting to see what percentage of renewables in a utility's fuel mix were from distributed generation as opposed to utility-scale generation but this data was not available. Data on how the percentage of renewables changed year over year would have strengthened this analysis as well. Additional IRPs and more data on utility fuel mixes would have strengthened this paper.

There was also a scarcity of data on utilities managed by women: only 27 utilities in our data set had a female manager. A recent article noted that the role of female leadership in the transition from fossil fuels to renewables has not been widely analyzed or even recognized (Allen et al., 2019). We had hoped to fill that gap in the literature and our data revealed that the average percentage of energy generated from renewables among male-led utilities was 29.7% and the average percent of renewables in the supply mix for female-led utilities was 36.5%. Due to the small sample size, however, the difference between these means was not significant. While the relationship between female leadership and renewables wasn't ultimately conclusive, it was certainly suggestive.

The results of the simultaneous equation estimation were unexpected and could be further explored in future analyses. Our results predicted that the more power a utility derives from renewables, the less likely they are to talk about renewables and efficiency. This could be due to a nonlinear relationship between the two variables, an event that is frequently evidenced in the literature on entrepreneurial orientation (Wales et al., 2013). There could also be a temporal element to the relationship between RO and percent power from renewables, as utilities with less renewable energy in their fuel mix plan for more aggressive installations in the future while utilities who are ahead of the curve on renewables deployment see less of a need to address it in their planning documents. Talking at length about renewables may occur when a utility is planning to invest in new renewables, but generation projects and the transmission lines that connect them to the grid can take a very long time to build so their intentions might not materialize in their current percentage of power from renewables. Another possibility is that many utilities that derive a high percentage of power from renewables may accomplish this by being located next to a large amount of cheap hydro-electric power or wind turbines and thus may be choosing renewables because they are cheap and readily available rather than because they have a strong renewable orientation. More granular data on the fuel mix or deconstructing RO into two separate dimensions of efficiency and renewability might shed further light on this finding.

There is also ample opportunity for examining the impact of different policy mechanisms, deregulation, utility ownership structure, and rurality on a utility's commitment to renewables. A deeper dive into the rural energy transition could unpack the social justice and NIMBY challenges that appear prevalent in rural communities and enable regulators to proactively address issues related to how and where renewable infrastructure is built. As more states consider deregulation a more focused analysis on the impact of a competitive marketplace on renewables could be explored as well.

One key finding is that it is going to take multiple strategies to achieve an energy system that embodies technical and social ideals. There is no one-size-fits-all solution and different areas of the country will respond differently to regulatory imperatives. By taking a stakeholder-centric perspective it is possible to target messaging and rate design in such a way that creates a collaborative and democratic process.

In conclusion, this data set provides a new window through which distribution utilities can be observed and their commitment to renewables measured against that of their peers. The words they use in their planning documents and the percentage of renewables that make up their fuel portfolios reveal varying levels of proactiveness as each utility balances environmental priorities with customer and shareholder values. As federal and state regulators look to design the right mix of policy instruments to increase the penetration of renewables, the theory and practice of entrepreneurial orientation can make a significant contribution.

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Chapter 5

Conclusion

Novel problems require novel solutions. Both the supply and demand side of the electric grid are fundamentally changing. Existing policies like the demand charge are no longer suitable to manage an increasingly dynamic grid. Meanwhile new innovations are bubbling up from niches, leading to increasingly complex demands from residential consumers and supply resources that are less easy to control. As a vision for a transformed power grid crystallizes, both utilities and their customers will need to redefine their relationships and rethink existing systems.

Table 5.1. Summary of key findings.

Study	Key Finding	Next Steps
Defeat the Peak	Pro-social incentives can effectively motivate energy behavior change.	Test program with different utilities and customer classes.
Re-Aligning Demand Charges	Demand Charges need to change in order to support innovation and decarbonization.	Collect global examples of price allocation strategies and compare all new options.
Renewability Orientation	Inter-firm, firm, and individual level factors deeply influence utility heterogeneity.	Explore rural resistance to renewables and impacts of regulatory decisions.

This dissertation built on Geel's Multi-Level Perspective to better understand key drivers of the energy system transition. At the sociocultural level we tested the power of pro-social incentives, revealing that appeals to community building and the common good can be effective invitations to democratize and amplify collaboration between residential consumers and electric utilities. We acknowledged that pro-social messaging is only one lever of change and that rate design and regulatory frameworks also play critical roles in the pace and success of the energy system transition.

The analysis of the demand charge demonstrated that this outdated revenue recovery mechanism was sending blunt signals that did not fairly allocate costs based on weather-based fluctuations in the price of power or incentivize commercial and industrial customers to work with utilities to reduce grid costs. Demand charges, however, are just one of many policies and processes that influence how effectively a utility is able to keep electric rates affordable while integrating renewables into their power supply.

The final chapter of the dissertation took a more sweeping view of many of the inter-firm, firm, and CEO-level factors that could influence the transition to renewables. This broader analysis looked at the varying experiments that were already being carried out in the electricity marketplace, identifying key policies and organizational dynamics that are most likely to coincide with renewability orientation in electric utilities. This exploratory research set the stage for more targeted analyses of key issues in the energy system transition, suggesting for example that the way that renewables are integrated into rural areas could be improved.

This research identifies multiple inflection points in the niche, regime, and landscape levels of Geel's sociotechnical transition framework. Distributed generation is manifesting as new niche level innovations for load control and storage that are increasingly recognized as important tools for achieving decarbonization goals. This recognition is causing regulators and utility managers to question their existing business models and find room for participants like aggregators to assist with load management. The landscape level is exerting further pressure on the status quo, as questions of resiliency and reliability loom large in an aging system plagued by increasingly severe weather events. Social movements and policy initiatives to increase generation from renewables are breaking down the path lock-in evidenced by certain utilities and inspiring others to lean into a distributed future. Characteristics of regime level players also play a key role in determining the pace and success of the transition. This dissertation supports Geel's MLP, finding important drivers of the energy system transition at each of the three levels.

5.1 Engaging with Residential Customers

Residential customers are being asked to participate in both active measures to curtail energy consumption when weather-dependent supply is low in addition to gradually decreasing their overall demand by investing in more efficient appliances. The traditional customer engagement strategy is purely financial, based on neoclassical economic program design. This paper looked beyond neoclassical economics to understand what else might motivate residential customers to respond to utility demand curtailment requests. The drive to bond and participate meaningfully in the community emerged from our literature review as a potentially powerful motivating force (Lawrence and Nohria, 2002b). We collaborated with the Burlington Electric Department to measure the impact of a program structured around the drive to bond where the incentive was a group donation to a local charity. Our results demonstrated a payback of $11 for every $1 invested in the program, findings that could help convince more utility managers to implement this type of program. Further, this confirmed our hypothesis that pro-social incentives can motivate residential customers to change their behaviour.

This customer engagement study could be greatly expanded upon amidst increasing demand for systemic change in power structures in the United States. Asking residential customers to postpone their appliance usage is just the tip of the iceberg. If the social side of the socio-technical transition succeeds then power structures will need to be decentralized and diversified. Residential customers of all backgrounds will need to be more engaged with decisions around siting, deployment of distributed energy resources, development of micro-grids, and many other power related decisions. Based on our research, outreach strategies based on altruism may be more effective at engaging with this wider audience than a purely financial strategy. Specific calls to support community goals through energy behavior change could mobilize residential clients in a way that is necessary to meet the full breadth of goals for the grid.

Further research could also investigate the impact of altruism-based programming for utilities with different characteristics. This study was executed in Burlington, Vermont with a municipal utility. Burlington, Vermont residents are highly sympathetic to climate-related goals and their utility has already succeeded in making Burlington 100% renewable (Peters, 2015). It would be interesting to repeat this test in other areas of the country and with different types of utilities to understand if the level of engagement is impacted by environmental and organizational characteristics. Further, initial testing by the Burlington Electric Department has showed promise for the use of non-financial incentives to drive energy behavior change for small to medium sized businesses. Small and medium enterprises are notoriously difficult to engage in energy programming (Máša et al., 2018). However, they often support their communities by supporting little league teams and other local initiatives. If participation in energy programming was positioned as a means of community support, small and medium enterprises may be more willing to engage (Jurik and Bodine, 2014).

5.2 Engaging with Commercial and Industrial Customers

In our second study we investigated rate design strategy for commercial and industrial customers. The demand charge which has served for over a century as a reliable means of cost recovery for electric utilities is no longer appropriate for a grid with weather-based supply. In order for utilities to generate least cost power, commercial and industrial customers need to flex their demand to available load. Our regression analysis explored a consequence of the current value-based pricing, as Bonbright describes it, that was designed to compete with independent generation rather than to recover marginal costs (Neufeld, 1987). We hypothesized that the result of utility reliance on the demand charge would be the shifting of grid costs onto residential customers. Indeed our model showed that residential customers pay a higher average electric rate if their utility derives a larger fraction of their revenue from demand charges. By updating the demand charge to align price and cost signals more closely, commercial and industrial customers could be incentivized to invest in distributed energy resources that lower overall grid costs, not just their coincident peaks. Ultimately this research suggested that the current demand charge rate structure cannot fairly and effectively support a weather-dependent decentralized grid.

This analysis was just a starting point, however, to a much larger discussion of how to update the demand charge. Multiple options exist for embedding more flexibility and dynamism into commercial and industrial rates. A modeling effort to understand the implications of different rate design mechanisms would be a useful follow-up study. As regulators struggle to weigh one option against another, additional data and scenario building would lend clarity to the selection process.

5.3 Engaging with Electric Utilities

Our third paper focused on utility engagement in the energy system transition. While some utilities lean into efforts to decarbonize and decentralize the grid, others take a much more conservative approach. We measured these differences by constructing a database of 170 electric utilities that had filed public Integrated Resource Plans. Using computer-aided text analysis (CATA) we created a novel dictionary, Renewability Orientation, to assess the frequency of renewability-related language in this key utility planning document. The resulting firm heterogeneity was analyzed through the lens of institutional resource-based theory, and factors at the inter-firm, firm, and managerial levels were all used to build a model to predict RO (Oliver, 1997). Ultimately we found that a constellation of factors will jointly determine how aggressively a utility is willing to lean into the energy transition.

The results of this study provide multiple opportunities for both expansion as well as more narrowly focused investigations. Our database includes numerous potential dependent variables, and future studies could revolve around models that predict a utility's entrepreneurial orientation, reliability, or the percent power that they derive from non-hydro renewables. Additional independent variables could be analyzed as well, such as the background training of the CEO, existence of net metering, state GDP, political orientation of the state, and public opinion towards climate change. Before asking new questions, however, it would be interesting to explore emergent trends from the model that we already created.

Our model suggests that utilities in rural states are less likely to talk about renewables and efficiency in their planning documents. When the state is deregulated and utilities need to compete for customers the effect is magnified. At the same time, utilities in rural states are more likely to derive power from renewables. This suggests that renewable energy infrastructure is being deployed in rural areas but that it is not viewed favorably by rural residents or utilities. This tension is critical to explore before increased renewable deployment exacerbates this underlying social tension.

Regulators in rural states need to re-examine the way that renewables are being integrated into communities, particularly if they are considering deregulation of utilities. Privatization of electric utilities appears to have a negative impact on the energy system transition, so regulators could consider converting privately owned utilities into rural coops and municipal utilities. Renewable Portfolio Standards are a good way to increase the penetration of renewables as well. Lastly, utility leadership needs to open up to some diversity. Over 80% of the utilities in my sample were run by men with an average of 18 years of experience in the power industry. This is not a group that is going to shake things up, and a regulatory push for newer and more diverse leaders could be positively impactful as well.

5.4 Future of Renewable Energy Innovation

The complexity of repurposing the grid to achieve social, environmental, and economic goals is significant. Innovation is at the center of this shift, pushing renewable technologies further than ever before, but it is hard to know if it is happening quickly enough. An aging infrastructure, heightened awareness of cybersecurity risks, and higher frequency of extreme weather events can create anxiety and fear amidst a population that depends on reliable energy for almost every part of their daily lives.

But amidst these harbingers of doom are seeds of hope. They emerge from entrepreneurs whose commitment to climate change mitigation motivates them to take huge risks to create load balancing solutions. It is visible in residential consumers as they rally together to curtail energy loads during peak events in order to support their community non-profits. Hope can be seen in regulators and policy makers who set ambitious goals for the reduction of greenhouse gases and work closely with utilities to question complex and longstanding policies in order to build a system that can handle new challenges. When seen in the context of these actions it is possible to believe that there is hope for an energy system transition that creates meaningful and positive change for both the social and technical elements of the power system.

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Appendix A: Word List for Renewability Orientation

Achievable Potential; Acid Rain; Additionality; Advanced Metering Infrastructure; Advanced Rate Design; American Recovery and Reinvestment Act of 2009; Behavior-Based Programs; Blower Door; Coincidental Peak Factor; Combined Heat and Power; Comprehensive Home Energy Audits; Critical Peak Pricing; Decoupling; Demand Response; Demand-Side Management; Distributed Energy Resource; Distributed Generation; Distributed Power; Emerging Technology; Energy Conservation; Energy Efficiency Measure; Energy Efficiency Potential; Energy Efficiency Resource Standard; Feebate; Flexible Fuel Vehicle; Fuel Cell Vehicle; Global Warming; Green Building; Greenhouse Gas; Heat Pump; High Performance Building; In-Home Display; Industrial Ecology; Load Shifting; Market Transformation; Peak Shaving; Plug-in Hybrid-Electric Vehicle; Post-Occupancy Evaluation; Real Time Pricing; Recycled Energy; Renewable Generation; Smart Meter; Time of Use Rates; Utility Restructuring; Weatherization; AFV; Biofuels; Biomass; C-BED; CIP; Cogeneration; Combined Cycle; Distributed Generation (DG); DSM; Energy Conservation; Energy Efficiency; Greenhouse gases; Greenhouse; Net metering; NEM; PACE; Property Assessed Clean Energy (PACE); PV; RDF; REC; Renewable Energy Certificate; Renewable Resources; RES; Renewable Energy Standard; RPS; Renewable Portfolio Standard; Societal Benefits Charge; SREC; Solar; Solar Renewable Energy Certificate; Unbundling; Wind; Turbine