A Prosperous and Cleaner Future: Markets, Innovation, and Electricity Distribution in the 21st Century

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Executive Summary

Technologically, we are on the threshold of advances in electricity that have the potential to profoundly change our lives. For it to happen, we must overhaul an outdated regulatory structure that was designed in the days of Edison and Tesla, when electricity's greatest challenge was to encourage the laying of wires. It must be replaced with an architecture that encourages and rewards experimentation and product development by a multitude of players within a vibrant, robust marketplace.

With two-way electricity distribution, digital technology and an integrated grid system, we may soon think not so much of "electricity," but, rather, of "energy—a commodity platform in which each of us will be both buyer and seller (and, for some of us, producer as well).

Imagine your home equipped with solar generators that power both your house and your car, with excess kilowatts sold in a healthy retail market with the distribution company providing a market platform. Think of devices within both your home and your car that will monitor and adjust your energy usage—both stationary and mobile—so you can maximize energy efficiency effortlessly.

The effect could well be transformative, portending enormous improvements in energy efficiency and, with them, significant reductions in carbon emissions. Products will be invented, services developed and jobs created.

The technology already exists. What is standing in the way is a regulatory structure better suited to the electricity markets of 100 years ago.

During the infancy of electricity, our greatest obstacle was to amass the massive capital resources needed to generate and distribute a reliable, safe and affordable power supply. Quite literally, we had to build an entire infrastructure, from the bottom up: power generators, transmission facilities, even the poles and wires that delivered electricity to our individual homes and businesses. Our singular policy goal was to incentivize the capital investment needed to assure safe, universal service at an affordable price.

Electricity was linear and vertically integrated, with electric companies providing every element of the product, from generation through transmission and distribution to retail. Electric companies developed into geographically contiguous, integrated enterprises that provided a basic, uniform and high quality service at a price the consumer could afford.

Sustaining such a large-scale, vertically integrated market structure required legal barriers to entry that protected the electric companies from competition. The regulated monopoly model maximized economies of scale, keeping costs low and stable for consumers.

Thanks to technological advances, however, the traditional electricity grid has been transformed: what was once a linear, one-way delivery of electricity from generators to the public has instead started to morph into a meshed, integrated electricity network marked by multi-directional flows.

Thanks to these advances, products and services like residential solar, microgrids and energy management devices are already available, with others just over the horizon—provided we can modernize our regulatory structure to keep paces with our technological advances.

What is needed today are incentives for new participants to enter the marketplace, not restrictions. For us to enjoy the fruits of the technological innovations that have already taken place, we must encourage our brightest minds to develop all manner of goods and services, both within the network and at its edge.

At stake is not just lower-cost electric power and a cleaner planet; in the balance, ultimately, are untold thousands of jobs in new industries that today we cannot even begin to imagine.

Let's learn from the lessons we were taught from development of the internet: minimal barriers to entry and incentives to innovation and experimentation led to an astounding array of goods and services—from Amazon to Uber and everywhere in between. A regulated monopoly, with cost-plus pricing and legal barriers to entry, would have suffocated these developments.

If our successes (and our failures) in adapting to the transformative technologies of the internet taught us anything, we will undertake a new regulatory superstructure for energy that is more suited to the challenges of the 21st Century than those of the 20th.

Introduction

Reconciling economic prosperity with environmental quality is a fundamental public policy issue, because the institutional framework in which we make choices has resource implications in both the near and the long term. Right now, no industry is more emblematic of this challenge than electricity, which has been both a primary driver of prosperity and also a major source of pollution and greenhouse gases when generated using fossil fuels. But the

[1] I am grateful to Mark Silberg for useful comments and editorial suggestions.

relationship between prosperity and environmental quality in electricity is a dynamic one, and can change as a function of both the institutional framework and dynamic factors like technological change. In fact, technological change and innovation are in large part a consequence of the incentives the institutional framework creates. Those incentives affect entrepreneurship in infrastructure for a 21st century electricity distribution network: cleaner energy technologies, digital energy and smart grid technologies, and energy efficiency.

The digital technology that allows us to flourish in unanticipated ways is an expression of human creativity in an environment in which experimentation is rife and entry barriers are low. That combination of experimentation and low entry barriers is what has made the Internet such a rich, interesting platform for us to use to make ourselves better off, in the different ways and meanings we each have. These digital innovations are possible because the Internet provided a platform for "permissionless innovation."

Vint Cerf, one of the original creators of the Internet, attributes the pace and impact of innovation to the network's bottom-up, distributed creation, and its nature as a platform for "permissionless innovation":

> *When I helped to develop the open standards that computers use to communicate with one another across the Net, I hoped for but could not predict how it would blossom and how much human ingenuity it would unleash. What secret sauce powered its success? The Net prospered precisely because governments—for the most part—allowed the Internet to grow organically, with civil society, academia, private sector and voluntary standards bodies collaborating on development, operation and governance. (Cerf 2012).*

The Internet's open architecture (open communication protocols and interoperability) makes creating new devices and applications layered on top of the Internet easy and inexpensive within the context of technical rules and commercial law. The Internet is a technology platform, with a core set of technologies and a set of emergent rules about interoperability and open interfaces at the edge of the network. No regulation existed to prevent entrepreneurs from creating new ideas, products, services, markets, or applications around this platform using these common protocols. In electricity, though, the form and extent of economic regulation may act as a permission barrier, preventing such unexpected benefits from arising.

Such digital innovations are now affecting energy, entering the electricity industry and enabling dramatic changes in how we produce, consume, and monitor electricity, as well as changes in the environmental impact of electricity consumption. Imagine, for example, the "connected home": customizing your built environment with digital sensors that enable preset and automated lighting, air conditioning, or refrigerator changes automatically as electricity prices change, or when renewable power becomes available.

Smart grid technologies embedded in the electricity distribution network enable automated outage notification, fault detection and repair, and routing of current flows around faults to maintain service. They also enable the interconnection of increasingly heterogeneous devices, owned and operated by increasingly heterogeneous types and sizes of agents. A homeowner can own an electric vehicle, enabling both consumption and generation of electricity. Microgrids can connect a neighborhood of individuals and technologies capable of consuming, generating, or both, large and small.

In the traditional, linear electricity value chain, large generators send energy to end-use customers via high-voltage transmission and low-voltage distribution networks intermediated by transformers. With smart grid technologies, multi-directional connection and current flow in a physically stable distribution network are now possible and open up new opportunities for innovation and intelligence at the distribution edge, similar to the Internet.

The electricity industry is subject to dynamic economic, technological, and policy environments that have changed substantially over the past century. Many of these changes are concentrated over the past three decades. Among these broad changes is the proliferation of digital communications that have increased the use of new technology to automate or perform tasks on our behalf. New electronic communications have the potential to create disruptive technological and financial changes in the electricity sector, and, indeed, to change the nature of the system itself due to the distributed "intelligence at the edge of the network" nature of digital technologies. However, the regulatory institutions governing the electricity industry, crafted in the early 20th century, favor incumbent and historical electro-mechanical technologies, which, in the past, had tremendous economies of scale and required vertically integrated firms to provide customers with reliability and affordability–and only reliable and affordable electricity. These regulatory institutions embed and rigidify regulatory and business models based on those technologies.

At the time of their enactment in the early 20th century, electricity regulations also were not focused on the environmental impact of the power system. As environmental challenges have become more salient, governmental and regulatory agencies have failed to synthesize competing regulatory mandates–electric reliability, affordability, and environmental protection– into an internally consistent structure. Instead, the current amalgamation of economic and environmental regulations governing the electricity industry does not facilitate the discovery of optimal economic and environmental outcomes, or how to align economic and environmental objectives in such a crucial industry.

One critique of retail electricity regulation is its inability to adapt to unknown and changing conditions (Kiesling 2008). Because regulation stipulates product definitions, product quality, and market boundaries, it rigidifies processes that are usually dynamic and fluid in other markets. Regulation erects legal entry barriers into the distribution and (in many places) retail sale of electricity to residential customers, so it entrenches the historical vertically integrated organizational structure of the regulated firm, despite the very real possibility that innovation has changed the transactional boundary of the firm. In this sense, the utility business structure is a regulatory construct. Traditional electricity regulation is static and formulaic, as befits a set of institutions designed to foster infrastructure investment in specific technologies with an objective of universal service at lowest financial cost. Procedural protections, such as the process of pursuing rate cases and rule changes allowing time for public comment (Administrative Procedures Act), increase the transparency of regulation in striving for this objective while also providing some bulwark against the public choice dynamic of concentrated interests being able to control processes and determine outcomes. These procedural protections mean that change happens slowly, which has its benefits because these investments are costly and long-lived, so prudence is a high-priority virtue. Prudence is also a virtue here because regulators are acting as agents, custodians, and stewards of ratepayer resources. They are not making investment decisions using and risking their own capital alone.

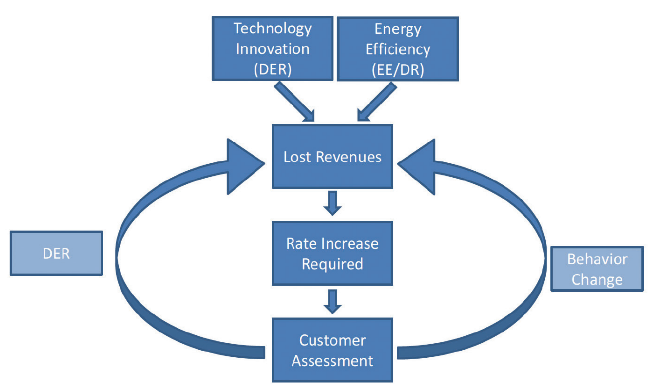
The technological dynamism of the 21st century is a broad expansion of general-purpose technologies with powerful decentralizing forces. These forces are changing what people see as valuable and how they achieve what they want to achieve in their lives. One thing they are changing is the opportunity cost of electricity regulation. When few alternatives exist to the electro-mechanical distribution grid and standard commodity electricity service, that opportunity cost of regulation is relatively low. As digital and distributed energy technologies (for example, such as some wind and solar power) have evolved, more alternatives are available or could be available through entrepreneurial action. Consumers could prefer those alternatives, if they had opportunities to experiment with, say, in-home transactive devices that could automate appliance responses to electricity price changes, or a retailer bundling home energy management with home security, or residential rooftop solar. But the only way producers have incentives to create and consumers to try new options is through their mutually beneficial interactions in markets.

The idea that permissionless innovation promotes widespread improvements in well-being should be a guiding principle as we think about regulation and market design in retail energy markets. Legal entry barriers, the bureaucratic procedures for cost recovery, the risk aversion of both regulators and the regulated, all undermine the processes that enable innovations to yield both consumer benefits and producer profits in a future environment generated by new opportunities. Regulations that dictate business models limit the exploration of potential opportunities that benefit society.

Technological change from outside the utility industry is now creating such opportunities. Smaller-scale distributed generation and other distributed energy resources (DER) such as energy storage and Internet-connected appliances are increasingly economical, placing pressure on the regulated distribution utility model. A 2013 Edison Electric Institute analysis sparked an ongoing debate over the financial implications of disruptive technological challenges for the traditional distribution utility business model, focusing on the question of revenue generation for the distribution grid. The report draws parallels to the decline of the wires telephone company in an increasingly decentralized and distributed system (Edison Electric Institute 2013). Figure 1 illustrates the pressures that distributed technologies place on the traditional distribution utility business and regulatory model.

FIGURE 1

The "utility death spiral"



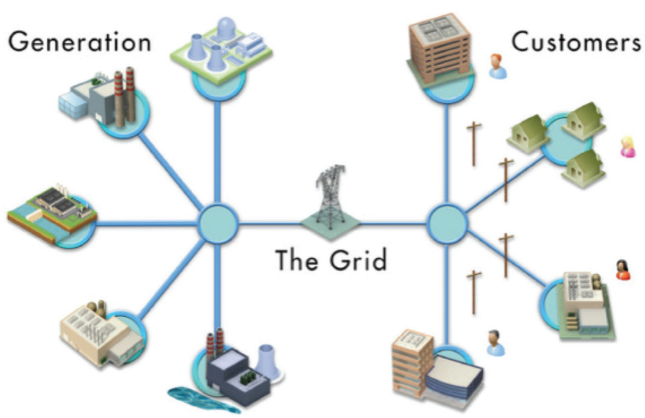
Source: EEI (2013), p. 12.

A May 2014 Barclay's report recommended down-weighting of electric utilities in investment portfolios due to the financial pressures likely to arise from "grid defection," although other analyses suggest that the economic value of the assets and functions in the distribution utility are not likely to erode as quickly as seen in the telecommunications industry (Barclay's 2014, Rocky Mountain Institute 2014). The pace of change is, in part, a consequence of consumer psychology; while grid defection may be economical in the short- to medium-term, particularly in markets with relatively high retail electricity rates, consumers may still not feel comfortable "pulling the plug".

Figures 2 and 3 illustrate the differences in the existing and the potential distribution system resulting from technological dynamism in the form of smart grid and distributed energy technologies. Figure 2 represents the traditional, linear physical flow and value chain in the industry, while Figure 3 presents a schematic of the multi-directional flows of both physical current and value creation that are possible with such innovations.

FIGURE 2

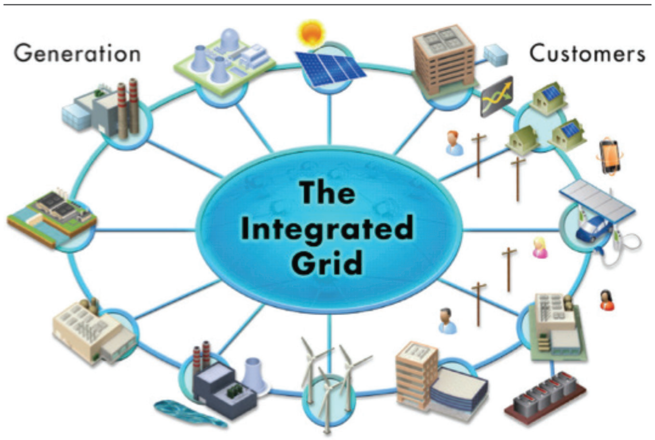
The Traditional Electricity Grid



Source: EPRI (2014), p. 8

FIGURE 3

A Meshed, Integrated Electricity Network



Source: EPRI (2014), p. 31

These digital distribution technologies enable innovation at the edge of the network, similar to that created in the Internet over the past two decades. Such welfare-enhancing creativity is possible in electricity, as seen in residential solar, microgrids, electric vehicles, and applications and devices for autonomous and mobile home energy management. These issues also have environmental and long-run conservation implications.

This paper explores electricity regulation and how it has affected incentives to innovate, including innovations in clean energy, energy efficiency, and grid infrastructure. I analyze regulatory institutions using a more dynamic theory of competition grounded in experimentation and emergent social learning, and use that theory in conjunction with other recent research to propose an alternative regulatory and utility framework. By emphasizing experimentation and the role that social institutions (including regulation) play in the process of technological change, this paper provides a new analysis of innovation processes in a capital-intensive historically regulated infrastructure industry, focused on facilitating innovation while also aligning economic and environmental objectives.

The connection among innovation, environmental quality, and retail market competition and consumer choice in electricity is important, but overlooked. If our policy objective is designing regulatory institutions that align economic and environmental incentives, the effects of regulation on innovation and consumer choice will be crucial aspects to consider as we work toward a prosperous and clean future.

How Regulation Influences Innovation and the Utility Business Model

The institutional framework of regulation (or the policies that shape the utility business model and the incentives of regulators, utility executives, consumers, and entrepreneurs) is one of the most important factors affecting energy innovation and a cleaner future. In the U.S., that framework determines the scope of experimentation, innovation, and incentives facing utilities and energy businesses.

Understanding economic regulation, and its effects on both innovation and conservation, is impossible without understanding its history and origins in 19th century technology and culture. That system of economic regulation is embedded in the current regulatory and business culture, institutions, and incentives facing regulated utilities, regulators, consumers, and entrepreneurs.

Although the electricity industry has had heavy economic regulation almost since its inception, concerns about environmental quality are relatively recent in electricity's history. Regulatory institutions have not changed much over the past century when compared with the broader changes in the economy and technology. Thus, the culture of regulation is deeply embedded in the regulatory commissions, in the organizational structure and business culture of regulated firms, and in the consumer advocates and interest groups that participate in regulatory proceedings.

For over a century, regulation has been a pervasive construct that shapes the incentives facing those parties, and institutions and incentives shape cultures just as much as cultures and beliefs give rise to institutions. Regulation initially emerged as a planned, designed response to Progressive Era concerns about firm size and market power in the late 19th century, when technological change and innovation took the form of large-scale production and manufacturing technologies that enabled goods, both existing and new, to be produced more cheaply when produced at much larger scale. The Supreme Court decision in *Munn vs. Illinois* (1887) established the precedent that such regulation of commerce could be undertaken if it served the public interest. The new electric lighting industry ultimately experienced such regulation.

Electric lighting was the iPhone of the 1880s, the transformative and trend-setting technology. Edison's Pearl Street facility's first customers were some of New York's most prominent economic and social leaders, such as J.P. Morgan, who was also an investor in the Edison Electric Company; in Chicago, early electric lighting adopters were Potter Palmer, Marshall Field, and other economic and social entrepreneurs (Munson 2005; Platt 1991). Electric lighting made a bright and visible social statement, with wealthy early adopters gaining notoriety and status from the novelty, increasing electricity's appeal to other customers, and also serving as test cases for Edison (and later others), as entrepreneurs tinkered with this new technology and improved its mass-market viability. As seen in the history of technology in other industries, early adopters pushed companies toward mass production, ultimately leading to lower costs and thus lower prices.

Competition and patent races among inventors drove a furious pace of electricity invention from the 1870s onward, culminating in the "war of currents" between Edison's direct current (DC) design and business model, and Westinghouse's (and Tesla's) alternating current (AC) system. Edison's direct current system required generation relatively close to consumption, connected by a costly and increasingly dense distribution network. Westinghouse's AC system, using ideas and patents from former Edison employee Nikola Tesla, allowed development of remote, large-scale generation connected to distribution systems via high-voltage transmission wires. Another technological development—William Stanley's transformer—allowed AC electricity to be carried long distances at high voltage using less expensive wires more efficiently than DC. While expensive, the scale of these generation and transmission systems could serve hundreds of thousands of customers. AC and its lower average cost, driven primarily by economies of scale, prevailed. By the late 1890s, electricity joined rail, telephones, and natural gas networks as an infrastructure industry shaped by economies of scale and organized using vertical integration to capture those economies.

The war of currents resulted in an architecture for a particular electric power system design, built primarily on the ideas of Tesla and Westinghouse. The distribution system requires real-time balance between supply and demand, relying on mechanical switches and capacitors to serve as buffers to maintain reliable service. Mechanical watt-hour meters captured a running record of the total number of watt-hours the end user consumed. Distribution networks were also designed for one-way delivery of energy from generators through substations to end users, based on the then-reasonable assumption that power would always flow from centralized generators to customers. This system provided the technological origins of the vertically integrated firms in the electricity industry.

This electro-mechanical technology and one-way network architecture has had significant economic implications, most notably the high fixed costs associated with constructing large-scale generation facilities and transmission and distribution infrastructure. The traditional structure and regulatory environment in the electricity industry are due primarily to economies of scale and scope; thus the electricity industry has existed over the past century as a natural monopoly. A defining characteristic of natural monopoly is declining average costs over the relevant range of demand.[2] The primary source of this characteristic is the high fixed cost required to build the infrastructure necessary to serve customers. Low marginal cost (e.g., low fuel and labor cost when compared to the capital costs) is not necessary for the existence of economies of scale, but empirically the combination of high fixed cost and low marginal cost has characterized large-scale central electricity generation since the early 20th century.

The AC system became the technological standard and is the foundation of our existing network architecture, and the vertically integrated firm was entrenched as the dominant utility business model. Vertical integration also emerged due to high transaction costs; early electro-mechanical technologies did not make arm's-length

[2] For the more technical definition of a multi-product natural monopoly and its necessary and sufficient characteristics, see Kiesling (2008) Chapter 2.

independent contracts possible between an independent wires company and an independent retailer, so electric companies provided integrated products and services from generation through transmission and distribution to retail. Thus, the structure of this industry from the early 20th century onward has been geographically contiguous, vertically integrated electric utilities, each serving customers in their geographic footprint with a basic and uniform, but high quality, undifferentiated service.

Large-scale generation at a distance contributed to environmental quality as well, by removing generation from densely populated areas and situating it in remote areas where air pollutants could diffuse without significant human harm. Over time, though, economic growth meant that population centers grew out toward generation plants, which showed that the margin between environmental/health impact and economic impact is dynamic and not fixed.

Sustaining a large-scale, vertically integrated market structure necessitated imposing a legal entry barrier to protect the monopolist from competition and maximize economies of scale, keeping costs low and stable for customers. The theoretical foundation of economic regulation of this vertically integrated industry has been the static natural monopoly model. A natural monopoly occurs when one firm can supply a market at lower cost than when smaller firms supply the same aggregate quantity. Natural monopoly arises primarily from economies of scale, generally in infrastructure industries with high fixed costs.

Natural monopoly theory suggests that regulation can keep retail prices low and stable, and can reduce costs by limiting infrastructure investment to a single, non-duplicative network. This model's framework and policy recommendations were consistent with the "public interest" theory of regulation in the United States during the Progressive Era.

Regulation was also consistent with the "public choice" theory that electric companies sought lower capital costs and more stable profits through regulation.[3] In the early years following Thomas Edison's pioneering creation of a new electric lighting industry in New York in 1882, growth and rivalrous market entry occurred, predominantly in densely populated urban areas where Edison's direct current system made economic sense. Customers in cities like New York and Chicago could soon choose among competing electric lighting companies, but as firms experimented with different strategies and markets developed, firms that were either better run or had better political connections (or both) expanded their market share, while less efficient firms exited the industry. When that happened, a surviving firm acquired the assets and customers of the departing firm, typically taking out debt to pay for the assets. This process led to consolidation and large market shares for strong incumbents such as Consolidated Edison in New York and Commonwealth Edison in Chicago.

High profits attracted entry, and this pattern repeated, which meant that the consolidated incumbent firm took on more debt, usually at a higher interest rate as debt loads grew. That cost led electricity executives, most prominently Samuel Insull of Commonwealth Edison, to argue in favor of industry regulation as a means of stabilizing markets and ensuring profitability while also ensuring low and stable retail prices to the most possible customers. Utilities and politicians began to see electrification as a path to economic growth. In Chicago in particular, Samuel Insull drove this value evolution aggressively, pricing residential electric service high enough to cover costs and provide a profit margin, but low enough to attract new mass-market residential customers to Commonwealth Edison (Munson 2005, Chapter 3). The company soon learned that success in the electricity industry, constrained by centralized generation and expensive wires technologies, required consolidation. Insull's role in pursuing the regulatory compact and regulation of his industry illustrates the public choice dynamic in regulation. Regulation of electricity distribution as a public utility thus arose out of the alignment of public interest and public choice motivations, leading to the regulatory compact: the regulated firm would earn a fixed rate of return on the assets used to provide energy to end users, in return for their agreement to serve all customers in their territory.

As a result, the 20th century saw public utility regulation accomplish many of the goals of its designers, with the industry achieving near-universal electrification and averaged retail rates that were low and stable. This success led the National Academy of Engineering to name electrification as the crowning engineering achievement of the 20th century (NAE 2000). This achievement occurred by putting "iron in the ground", building electricity infrastructure based on forecasting future demand growth and regulatory approval of the construction of new infrastructure, wires and generators, to meet that forecast demand. Over the first half of the 20th century, process innovation also made large-scale generators more energy efficient, which meant large coal-fired generators could generate more energy from a given amount of fuel. This process continued, contributing to economic growth and profiting from economic growth, until the energy efficiency and productivity of large-scale generation reached a plateau in the mid-1960s (Hirsh 1999). In the 20th century, regulation was well-suited to the industry's

[3] Public choice uses economic theory to analyze political decision-making. Modeling political actors as having rationally self-interested motives has led to a richer understanding of voting, lobbying, special interest coalition formation, and rent-seeking. See Shugart (2008).

growth—providing a stable infrastructure investment environment where debt leads to lower production costs and lower retail rates.

Innovation-Induced Unbundling in the 1990s and Today—Institutional and Organizational Change

Although the network architecture has remained largely unchanged, generation technology has not. Nuclear energy and then the combined-cycle gas turbine (CCGT) changed the economies of scale, and therefore the cost structure, of the generation portion of the value chain by introducing heterogeneous technologies into the mix.

Nuclear cost overruns exposed the limits of public utility regulation. In the 1970s, nuclear was expected to be unprecedentedly inexpensive ("too cheap to meter"), due to economies of scale and the very low marginal cost of generating an additional megawatt-hour of energy once the plant was running. In practice, that was not the case because of unanticipated high fixed costs. Cost overruns were passed along to consumers, creating controversy in many states, including California and Illinois.

A second significant technological change in generation occurred in the late 1980s. The combined-cycle gas turbine (CCGT) generator (basically a jet engine bolted to a platform) enabled economical generation at smaller scale. As a consequence, the monolithic, ever-decreasing average cost across the industry was no longer true, weakening of the economies of scale in generation (although they still existed in the wires). This technological change made competitive wholesale electricity markets feasible due to changes in cost functions and economies of scale in generation.

Nuclear and CCGT technologies led to the federal and state regulatory restructuring of the 1990s. The Energy Policy Act of 1992 opened up wholesale markets and charged the Federal Energy Regulatory Commission (FERC) with monitoring them to ensure that market prices were "just and reasonable". As wholesale markets developed, several states implemented state-level restructuring to take advantage of competitive wholesale markets, spurred on by the nuclear cost overruns. With reduced economies of scale in generation and the growing wholesale markets, generators could operate as independent power producers rather than the traditional vertically integrated utilities they had been for almost a century. Regulatory restructuring thus opened wholesale markets to competition by reducing legal entry barriers and led to the unbundling of the generation portion of the supply chain from the vertically integrated firm. Fifteen states and the District of Columbia have implemented retail restructuring and have some form of retail competition for some or all types of customers, and two-thirds of the electricity consumed in the U.S. is transacted competitively through one of the 8 organized regional wholesale power markets.

Today we are experiencing a second wave of innovation-induced unbundling, this time with production process innovation and new products and services in digital smart grid and distributed energy technologies. The economic and environmental implications of digital innovation arise within the context of a specific set of regulatory institutions. These institutions were designed to induce widespread electrification and low, stable retail prices in a stable investment environment. In a traditional regulated industry like electricity, firms were initially vertically integrated because of technological constraints. Large-scale generation and transmission technologies enabled production of standard electric power service at a particular voltage range with economies of scale over the relevant range of demand, and transaction costs limited the possibility of arm's-length trade among independent generators, independent wires companies, and independent retailers. Electric companies grew, consolidated, and became large. Their size and associated market power raised concerns about the welfare impacts of monopoly pricing, which dovetailed with industry concerns about their capital structure and led to state-level public utility regulation.

How does existing regulation affect the nature and pace of such change? What are some changes to regulation, and, in turn, to the utility business model, that can reduce barriers to such innovation? Answering those questions starts with a description and critique of existing regulatory theory and the theory of competition on which it is founded. This critique suggests an alternative theory of competition that can help us understand the process of innovation and regulation's role and impact. The connection between innovation and competition in retail markets is experimental learning through trial and error, which is an essential part of both the innovation process and of market processes more generally.

Regulation's Theory of Competition and Why It Matters Economically and Environmentally

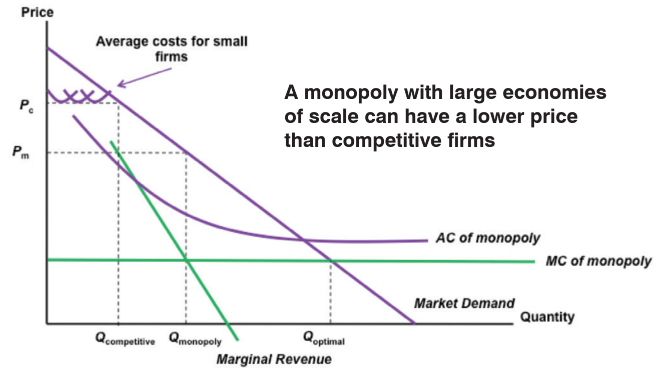
The economic theory underlying regulation frames the practice of regulation and the nature and pace of innovation. For the past century, economic regulation in the electricity industry has been based on natural monopoly theory. This model describes an industry with decreasing costs of producing a specific product. Both the definition of the product and the demand for it are given and unchanging. The model suggests that the natural equilibrating tendency in a rivalrous market with multiple competitors is to charge a price that does not cover the substantial fixed costs. Therefore, as the designers of this model argued in the 1890s, economic regulation should erect an entry barrier, grant a monopoly, and stipulate that the firm's profits will be a cost-plus rate of return on assets. The regulator has the information about the firm's costs to enable him/her to determine what that rate of return should be. Such regulation will lead to the provision of that given product to those given consumers at the lowest feasible cost. Thus, economic regulation itself defines the boundaries of the market and the product. It accommodates demand growth simply by scaling up permitted infrastructure investment.

Traditional regulatory procedures focus regulators and the regulated on providing a narrowly defined, generic, highly reliable service at the lowest possible cost. As long as the industry is economically and technologically static, and growth occurs only as a scaling up of existing products and services, the regulatory model should be unchanged as well.

Using this static model assuming full information, the regulatory theory question is how to maximize total surplus given the technology, cost function, and consumer preferences. This question is inherently static. Compared to the efficient benchmark where firms compete by lowering price to marginal cost, a natural monopoly industry/firm/cost structure cannot sustain the competitive outcome where price equals marginal cost due to high fixed costs. In other words, with competition, electricity firms would be incentivized to each develop their own networks in parallel, leading to higher average costs for customers. Ensuring that a natural monopoly remains a monopoly, thus, insulating the firm from competitive pressures, actually produces better long-run outcomes. The level of output that would be profitable in an environment with high fixed costs and low entry barriers occurs where price is equal to average cost (where economic profits are "normal"), but this point is not a stable equilibrium. The reasoning in this case is that, with low entry barriers, the firm achieves its market power through consolidation as its competitors exit; it then can charge a high price, which would attract more entry, the rivalry of which would reduce the price to below average cost, inducing less efficient firms to exit, which enables the incumbent to raise its prices again. The point where price equals average cost yields the highest feasible total surplus given the nature of the cost function, and the natural monopoly model suggests that regulators should target that point through their regulations. Figure 4 represents this static model graphically.

FIGURE 4

The static natural monopoly model



Source: Cowen & Tabarrok (2011)

This static model is the justification for regulation of prices and quantities in this market, to make the quantity at which price equals average cost a stable outcome when, in the absence of regulation, it is not stable. Based on these assumptions, legislators, regulators, and industry converged on the current regulatory design, which in the US takes the form of rate-of-return regulation to target utility profits at "normal" levels, deriving retail prices from that, and erecting an entry barrier to exclude rivals while requiring the firm to serve all customers in a specific geographic territory.

Many of the assumptions of this regulatory model are increasingly untrue in our modern society. The assumption of a single production technology with a declining long-run average cost curve has long been incorrect, as shown by the smaller-scale combined-cycle gas turbine (CCGT) innovations in the 1980s and the ensuing unbundling of generation from the vertically integrated firm and liberalization of wholesale energy markets in restructured states in the U.S. This assumption is becoming even more problematic in the face of recent innovations in smaller-scale generation technologies, including natural gas, renewables, and even small modular nuclear power.

The current set of digital and distributed energy innovations make another assumption inapplicable: that of a fixed market for a well-defined product sold at a volumetric price. In the electro-mechanical era, this product was a bundled energy commodity and wires service, sold to consumers as a uniform, reliable product for which they paid a fixed, averaged price. Regulation reinforced this uniform product definition, and established quality measurements by which regulators could evaluate the utility's performance. Digital and distributed energy resources (DER) innovations have made this assumption overly simplifying. Digital meters and transactive end-use technologies will make time-differentiated dynamic pricing more possible and attractive to consumers, especially if they can automate their responses to these price signals. Digital technology enables fixed "green energy" products to evolve into contracts that enable consumers to tailor their "green-gray mix" to their budgets, which may (or may not) enable more consumers to buy energy according to their environmental preferences given their budgets.

In addition, assuming a flat volumetric price for electricity has efficiency implications for the grid as a whole. Currently, without price signals to curtail demand, electric systems must be built with sufficient capacity to account for rare but significantly higher electricity consumption during the peak days and hours, such as the hottest summer afternoons. Peak generators not only are used infrequently: they also are the most expensive and often most polluting resources on the grid. Even on small scales within the existing regulatory structure, demand-side management programs, where customer air conditioners or thermostats are programmed to respond to high prices, have shown dramatic cost, electricity, and pollution savings during peak events.

Another important assumption of the static model relates to assumptions about knowledge. The static model assumes regulators have access to all relevant knowledge to achieve the outcome where price equals average cost.[4] In fact, neither regulators nor other market participants have access to the knowledge influencing individual decisions made about production or consumption. In dynamic markets with diffuse private knowledge, neither entrepreneurs nor policy makers can know *a priori* which goods and services will succeed with consumers and at what prices. Similarly, consumers' preferences are not fixed and known, either to others or even to themselves. Consumers learn their preferences through the process of evaluating available choices in a marketplace, and analyze the relative value of those tradeoffs over time. Even the set of available consumer choices changes due to entrepreneurial activity. Only in the process of evaluating the tradeoffs and opportunity costs in their electricity consumption decisions do individual consumers learn opportunity costs, and that knowledge is unavailable to bureaucrats or regulators except through transactive market activity, where demand for particular goods is coordinated through market prices.

In particular, regulation stifles the social learning that occurs through experimentation that happens in market processes, because regulation presupposed demand and pricing *a priori*, not through a learning and experimentation process of consumers and producers. The learning aspect of market processes is crucial for enabling economic and social coordination, because knowledge is diffuse among the individual agents in society (Hayek 1945, 1974). Modern electricity regulation embodies the antithesis of this idea.

Regulatory models premised on cost recovery fail under pervasive economic and technological change—Schumpeterian creative destruction. Technological and economic dynamism characterizes the market environment of the early 21st century. As Joseph Schumpeter put it (1934, 1942), value arises through the collapse of product and service definitions, and market boundaries. Traditional economic regulation is designed to curtail such value-creating innovation and evolution.

Entrepreneurship theory suggests a more dynamic theory of competition. Joseph Schumpeter's (1934) pioneering analysis examined how disruptive innovation creates economic growth via individuals who create "new combinations" of materials and forces, leading to change away from economic equilibrium (1934, p. 65). Individuals discover these "combinations" by experimentation. Existing producers differ from these experimenters in their tendency to initiate growth-generating change by participating only in existing markets, producing only existing goods and services, using existing techniques at marginally lower prices.

Schumpeter enumerates fives mechanisms for creating dynamic change in markets: 1) introducing a new good or service, or adding new features to an existing one, 2) introducing new production technology or methods, 3) opening new markets, 4) capturing new sources of raw materials or 5) new methods of industrial organization, such as . , . (1934, p. 75). Competition in free-enterprise societies is a process of creative destruction, with new combinations and ideas making previous ones obsolete (1942, 84). Dynamic competition often takes the form of product differentiation and bundling to compete for the market. Rivalry occurs among differentiated products; innovators and entrepreneurs change market definitions and boundaries by creating new products and services as well as new bundles of products and services. That dynamic discovery of new value propositions necessarily takes place in an experimentation process in which different producers interact, as do old and new combinations, to meet the market test of consumer value creation.

Schumpeter's disruptive innovator finds its complement in the activity of Israel Kirzner's alert, aware, entrepreneur (1978, 2009). The "entrepreneur-as-equilibrator" (2009, p. 147) uses *differential alertness* to profit, at least speculatively, from an existing opportunity to create value. Differential alertness is awareness of a business opportunity that is otherwise underappreciated. This entrepreneur is not Schumpeter's "disruptive creator" but instead engages in

[4] One of the most fruitful areas of regulatory theory in the past 30 years has been the application of models of asymmetric information to the regulator's problem (e.g., Laffont & Tirole 1993). This work focuses on information, which the regulator can acquire at a cost; it does not address the epistemic questions of diffuse and private knowledge that are the subject of this discussion, and are inherently difficult to aggregate in the absence of a system of prices.

trial-and-error, playing a coordinating role by adapting to underlying changing conditions. Commercializing new products and services, as well as new bundles of products and service, is an example of "equilibrating entrepreneurship" as Kirzner understood it.

These ideas of entrepreneurship and experimentation are relevant to regulatory institutions and institutional change in electric power because decentralized coordination through market processes offers forward-looking coordination of behavior that is not available to central authorities, including regulators, no matter their expertise. Markets offer agents of all types the opportunities and incentives to make profitable discoveries through experimentation. Regulation as it is currently practiced does not.

The digital revolution of the past three decades provides insights for policymakers as they design regulatory institutions to promote consumer welfare through competition. Decades of technological dynamism and the value it has generated show that the means by which competition creates value is Schumpeterian creative destruction. New products and services that consumers value make existing ones obsolete. Creative destruction leads to economic growth and increased living standards, and in a dramatically different social-technological-economic system from the one that existed three decades ago, or that anyone could have foreseen three decades ago. Some examples of how creative destruction has transformed daily life include ATMs, mobile devices, and online commerce. These opportunities for entrepreneurial discovery by both producers and consumers have yielded value-creating, living standard-improving innovation and change.

The critique of the static natural monopoly model and the evidence of our current technological environment suggest that a more dynamic theory of competition should inform regulatory institutions for a 21st century electricity industry. Particularly in the past 50 years, with the advent of digital technology, the growth of economic activity as more transactions shift out of firms and into markets, globalization, and fundamental demographic and labor market changes, the environment in which the electricity industry operates is extremely dynamic and fluid.

Traditional economic regulation is incompatible with economic dynamism, with technological change, with innovation, and ultimately with widespread consumer well-being, because traditional economic regulation stifles consumer and producer experimentation. Market processes are valuable because they provide the ability for consumers and producers to experiment.

For those reasons, I take as a conceptual benchmark the extent to which a policy fosters experimentation. Experimentation means undertaking actions to discover something unknown, and is the hallmark of how market processes create value in a dynamic rather than a static sense (Kiesling 2014). Development by entrepreneurs of new products or services and bringing them to market are acts of experimentation. When a consumer walks in to a store, explores what mobile communication devices are available, what features they have or lack, and their prices: that is an act of experimentation. When enough consumers choose a specific product and get consumer surplus from that choice, the producer profits; when consumers do not choose a product, or choose it and end up not getting consumer surplus, the producer earns a loss, and error correction will involve either changing the production process and price, changing the product, or leaving the market. The interaction of producer and consumer experimentation through market processes over time yields commercial innovation, an example of which being the compound consequences of the Industrial Revolution (Mokyr 2010). The process also ensures that producers who are underperforming are eliminated from the marketplace.

Experimentation is among the most substantial drivers of value creation in an entrepreneurial theory that emphasizes competitive market processes—the ability of producers to bring new ideas to market, of producers to combine and bundle existing and new products and services in novel ways, and of consumers to discover these new value propositions and learn how much to value them. Yet despite the clear benefits, these concepts have not yet been integrated into the electricity sector.

Everett Rogers (1962) identifies experimentation as one of the primary factors influencing the diffusion of innovation. Shane Greenstein (2008, 2012) argues that economic experiments played a significant role in creating value in the markets for Internet access. His analyses suggest that although economic experimentation is a driver of value creation, pre-1990s federal spectrum policy erected a regulatory barrier to such experimentation. The technological, entrepreneurial, and regulatory parallels between the Internet and the electricity industry are stark. Just as much as deregulation of the Internet and telecommunications led to an explosion of innovations at the edge of the network, so, too, can this process happen with the electric industry, at the distribution edge.

Increasingly, as (1) smart grid technologies (as defined in the introduction) proliferate in the distribution network, (2) distributed energy resources become cheaper and more energy efficient, and (3) the "Internet of things" like smart appliances enable the "connected home", the existing permission-based regulation limits how much innovation occurs at the edge of the distribution network. The potential economic and environmental value from digitally enabled residential energy innovation will raise the opportunity cost of permission-based regulation, as the value of what could happen that regulators are not allowing to be discovered will be higher than in the traditional "electricity as a commodity" view of this market.

If it stifles innovation, such regulation is not necessarily benefiting consumers. By weighting toward the status quo, regulation may, in fact, harm consumers. Even if regulation was initiated as a mechanism for protecting consumer interests—and was effective in doing so—the administrative and legal processes it requires entrench interests to maintain the regulatory and technological status quo. Public choice theory and historical observation of regulated industries show how regulation becomes industry-protecting regulation. Industry-protecting regulation cultivates constituency interests, and those constituency interests tend to thwart innovation and retain entry barriers. The relevance of this issue is clear from ongoing debates around utility interconnection and third-party and consumer experimentation in electricity. This political economy dynamic between regulators and the regulated contributes to stifling of innovation.

Innovation, Regulation, and the Distribution Company of the Future

What would a focus on experimentation and reducing barriers to innovation imply for business models and organizational structure for the electric distribution company? What may the distribution company of the future look like? Which transactions would fall within its footprint? What does the emphasis on experimentation and innovation imply for retail market design and rules regarding market competition? Finally, what does it require of regulatory institutions and the role of regulation in a world rich with digital and DER technologies having dramatic decentralizing properties?

Suppose, for example, that a homeowner has distributed generation installed, such as rooftop solar panels. Other digital technology allows the customer to automate appliance use to vary electricity consumption depending on the output from the solar system, thereby reducing the use of energy overall and reducing the use of fossil-fuel-generated power procured through net metering from the grid. If an open, real-time retail market existed, the customer could sell any excess generation from the rooftop panels and make money to offset some of the investment expense. Digital technologies make such an open, decentralized, interconnected retail market possible at the edge of the distribution network. These communication technologies enable new value creation, reduction in environmental impact, and decentralized coordination in the electricity industry precisely because they make more of the network, and more of the participants in the network, transactive. Existing regulations in some states allow net metering and require utilities to provide energy efficiency programs while retaining fixed retail prices. These regulatory programs are poor administrative substitutes for such a rich and diverse set of value propositions, made easier and more valuable because technology enables simultaneous customization of services and automation of actions and decisions.

The value chain in electricity is complicated, due both to the physics of current flow in an alternating-current system with little energy storage and to its history of retail rate regulation. However, decentralized coordination is increasingly possible in the electric power industry because of the promise of digital technology. Imagine a vibrant market with rival retailers competing to serve end-use customers by offering them menus of contracts; these contracts may provide differentiated products and services, depending on the form of pricing and how it varies over time (fixed, time of use, real time), the type of generation resource (green/grey mix), the other goods and services with which the electricity service is bundled (security, health monitoring, entertainment), and other potentially valuable product dimensions that we cannot conceive of today but that entrepreneurs will strive to create through new market incentives.

Intelligent end-use devices make these products and services both feasible and attractive to consumers, because they provide consumers with information about their consumption, their expenditure, and the environmental impact of their consumption, and because these devices are transactive. The real value from a network of transactive devices and retail consumers is not limited to consumer and producer benefit in retail markets. Consider the aggregation of the (autonomous and manual) decisions that these customers have their devices make: dynamic prices increase when costs increase, and when demand is close to system capacity, and if consumers set their transactive devices to respond to price signals, in aggregate, demand will fall precisely when the demand reduction is most valuable. Price signals provide the focal point, the coordinating piece of information to which consumers (or, more accurately, their devices) can respond, and, in aggregate, their responses generate system reliability and reduce peak demand and "peaker" costs. In other words, this process of decentralized coordination leads to the kind of system-level order that has historically only been feasible through strict, centralized physical control of the distribution network.

This technology-enabled decentralized coordination is desirable because it connects the values and preferences of hundreds of thousands of consumers to the production and investment decisions of generators, using a system of price signals in market processes to coordinate the decisions of all of the parties involved in the consumption of electricity by retail consumers. This connection and coordination leads to economic efficiency, and can induce consumers to reduce their electricity use, leading to reduced resource use and reduced environmental impacts from electricity consumption.

Technological innovation is an evolutionary process, a discovery process with outcomes that no one can fully anticipate. Thus, if we want to learn what, if any, of these digital energy innovations at the distribution edge consumers find valuable, and how valuable they find them, experimentation is crucial. Experimentation through markets and coordinated via price signals enables producers and consumers to discover and create mutual value. This evolutionary process is the real reason why market competition creates value: decentralized market processes are precisely processes of learning, discovery, and error correction. From these processes, emergent order in markets creates system-wide efficiencies and outcomes that are otherwise impossible if centrally planned.

Policymakers seeking cleaner, economical electricity aim to influence this process to achieve their policy objectives, implementing technology-specific subsidies and carve-outs from renewable portfolio standards, for example. Policies that stipulate specific technologies that will be eligible for subsidies may induce growth in those technologies, but there is an unseen opportunity cost: the other technologies that could have been developed that may have been even cleaner, more economical, or more attractive to consumers. Policies imposing technology mandates stifle this dynamic experimentation process before it has even started, substituting policymaker judgment for the judgments of all of the producers and consumers subject to their control. Prescriptive technology policies narrow and focus the channel of innovation. That focus may yield some production economies of scale in the chosen technology, but at a cost of cutting off possibly beneficial exploration. Thus, we can evaluate the terms of the multitude of state-level solar-related policies active in a state like California based on the extent to which they foster the kind of decentralized experimentation, of both producers and consumers, as in the idealized dynamic market process described above (Kiesling & Silberg 2015).

Policy goals such as capacity targets for renewables are an attempt to guide and introduce specific technologies into an already perverse and distorted electricity market. The extent to which electricity markets foster innovation and experimentation should be a specific objective of future electricity market reform.

The Distribution Utility of the Future as a Technology and Market Platform

A useful outgrowth of the Internet, one that exploits this concept of permissionless innovation, is a business model for the electricity distribution company as a technological and economic platform that enables innovation at the edge of the network. Carliss Baldwin and Jason Woodard define a platform as "... a set of stable components that supports variety and evolvability in a system by constraining the linkages among the other components." (2009, p. 19) The distribution utility as a platform is a market design implication of technological change and the increasing complexity of the economic and technological environment in which firms in the electricity industry operate, and it is a consequence with implications for regulatory institutions as well. The organizational and business model of the distribution utility is a consequence of how regulation has been implemented, with the distribution utility having a legal monopoly over the physical distribution of an unchanging, well-defined product in a specific market with clear boundaries. In other words, only the distribution utility has the legal right to transport and sell energy of a particular voltage and quality to residential customers. Regulatory restructuring that enables retail competition has led to organizational change in some jurisdictions. Although here I focus on a design for the distribution platform business model, the changes required to enable such a model are regulatory changes.[5]

A platform is a collection of technology elements, typically with a stable, common technological core and a variable, heterogeneous periphery (Gawer 2014, p. 1242). Video game platforms are a canonical example—the core technology (the console) contains a set of (usually proprietary) elements working in conjunction with other, diverse elements (software) to enable gaming. Those diverse elements include games written to play on the platform, and other devices like joysticks that complement the core. A core of common components allows for economies of scope in production to develop around the platform, which is one of the main drivers of innovation in technological platforms. In the digital age, ownership of the platform almost always exceeds the value of any peripheral element. Examples include the iTunes store, iOS operating system, Facebook, and Uber. Savvy disruptive entrepreneurs, like utility executives in the 20th century, would benefit from establishing their innovations as platforms.

[5] The New York State Public Service Commission is exploring such regulatory changes and a move to Distribution Service Platforms (DSPs) as part of their Reforming the Energy Vision (REV) regulatory proceeding (New York State Public Service Commission 2014). Some of their design proposals are similar to those specified here, and this proceeding is likely to be the focus of electricity policy debate for the foreseeable future.

One aspect of platform firms is that they connect distinct and distant users in the network. Platform firms are network firms, although not all network firms/industries operate or think of their business models as platform firms. That will change as decentralizing digital technologies evolve further. The network or platform firm facilitates connection, enabling exchange between two or more parties. This idea is neither new nor original in the digital age. The economic history of the beginnings of canals or rail networks shows that transportation is a quintessential non-digital network platform industry. All network infrastructure industries have some aspects of platform or two-sided markets; rail networks bring together transportation providers and passengers/freight, postal networks bring together correspondents, pipeline networks bring together buyers and sellers of oil or natural gas, electric wires networks bring together generators and consumers. In that sense, they are economic platforms that enable two-sided markets.

An economic analysis of platforms views them as transaction facilitators and intermediaries. By using technologies that reduce transaction costs, economic platforms create value by enabling parties to connect for mutual benefit, typically in the form of exchange. Platform providers create markets insofar as they connect producers and consumers (Rochet & Tirole 2003). In the video game platform example, the platform provider creates value by providing a technology (the game console and its operating system) that acts as a focal point (Schelling 1960) for a game designer and gamer to transact; the exchange yields mutual benefit, and the existence of the platform provides incentives to developers to build games for the platform and the buyer to purchase new games. Thus, an economic analysis of platforms analyzes the platform as a two-sided market or multi-sided market, where the platform coordinates agents through transactions, price signals, and rules.

What is novel in the digital age is that by changing transaction costs, platform technology changes the transactional boundary of the firm and—unlike the innovations of the 19th century—reduces the economic impetus for vertical integration. A digital platform firm, like Google or Uber, is not vertically integrated upstream or downstream in any of the value chains that its platform enables (although some of Google's acquisitions are changing that somewhat), whereas historically, railroads and gas companies and electric companies started out vertically integrated. In fact, today, the reduction of vertical integration is welfare maximizing for platform firms, especially those like Uber who escape taxi regulations by being literally not a taxi service. In the past, rail network owners were vertically integrated upstream into train ownership and transportation provision, and electric utilities were integrated upstream into generation. In the past, these firms were incentives to veritically integrate and create monopolies. In network infrastructure industries, the platform is physical, and firms bundled the network service into their offering. But they have not been seen or thought of as platforms in the sense that we are coming to understand as such firms and industries emerge; I suspect that's because of the economic benefit and the historical path dependence of the vertical integration. The digital age makes this precedent obsolete.

At its core, a platform monetizes trust and interconnection among market actors—a driver and a passenger, a homeowner and a visitor, and soon, a power producer and consumer—and allows users to both bypass the central incumbent (such as a taxi service, hotel, or electric utility) and go through a new service provider (Uber, Airbnb, or in the power sector, Google).

Increasingly, as millions of consumers gain more experience and build trust with Airbnb, Uber, and Lyft, they may begin to ask why they have such an inflexible electricity system that is not focused on decentralized value creation in the way that other modern platform businesses are. Why couldn't a consumer share, sell, or buy the energy services of consumer-owned and -sited DERs like rooftop solar panels or smart thermostats? The answer may lie in emerging business models that enable peer-to-peer sharing of DERs. An electricity distribution platform is such a model.

Both Uber and AirBnB have business models which bring together parties for mutual benefit, and the platform provider's revenue stream comes from charging one or both parties for facilitating the transaction (although there are other means too). The core of a platform business model is to use digital technology and its powerful decentralizing forces to reduce transaction costs than can prevent mutually beneficial exchange. Platform providers exist to make exchanges feasible that were not before, to make them easier, and, ultimately, to make them either cheaper or more valuable (or some combination of the two).

A platform very explicitly reduces transaction costs, earning revenue via a commission or service fee per transaction. Throughout history, cars have been underutilized, guest bedrooms unused, and information was decentralized and inaccessible. Uber, AirBnb, and Google respectively turned these inefficiencies into market opportunities for buyers and sellers. The reduction of transaction costs through centralization, facilitation, and market-rule-making, allows owners of underutilized assets (cars, apartments, solar panels, and whatever else will evolve in the future) to make someone else better off by selling them the use of that asset. The static welfare gain to the two parties is obvious; but there is a dynamic welfare gain—you are more likely, all other things equal, to invest in such an asset or to invest in a bigger/nicer asset if you can increase its capacity utilization. Deregulation catalyzed this process in the airline industry, and digital technology is catalyzing it now in rides and rooms. This prospect is exciting for those interested in accelerating the growth of DERs, and particularly those interested in accelerating the growth of DERs through some means other than taxpayer subsidies and government renewable energy mandates.

The role of a distribution platform would be multifaceted, due to the core infrastructure nature of electricity distribution. Its primary role would continue to be its traditional core value proposition, the physical distribution of energy to end-users. For doing so, it would charge a wires tariff, in much the same way that unbundled wires charges are assessed in restructured markets currently. Physical reliability/supply security in the distribution network would remain a priority, and a wires platform company would be an appropriate party to be responsible for reliability (as distribution utilities are today).

A core function of a distribution platform will continue to be providing the distribution wires network. Given existing technology, and given initial conditions of existing physical distribution wires network, a "central backbone" distribution network is likely to continue to have economic value into the foreseeable future. To the extent that economies of scale and scope still exist in electricity distribution, a grid that is a central backbone will have value.

The distribution platform firm is the load-serving entity (LSE), with the operational and regulatory requirement to deliver electricity service to end-users. Accompanying that role are reliability requirements, with some administrative definition of what constitutes reliability, and the physical real-time network balancing function. The distribution platform is the orchestrator of grid needs, i.e., reliability, voltage regulation, and capacity. The distribution platform earns a normal rate of return and the revenue to maintain and modernize infrastructure through a wires charge to retail customers.

The defining feature of a platform firm is that it acts as an intermediary connecting two or more agents for mutual benefit, and the most common economic role of a platform firm is intermediation in transactions by providing a market platform that brings together potential buyers and sellers and makes it easier for them to find one other. Consider the analogy to financial market exchanges, such as stock exchanges or futures exchanges, which provide trading platforms. Attentive to the interests of both buyers and sellers, they define standard products and rules by which exchanges must occur, and offer timely and undifferentiated information for buyers to bid and sellers to offer, opening or closing new markets as the interests of buyers and sellers wax and wane. Beyond its physical roles, the electricity distribution platform firm would be a market platform.

As the end users become more heterogeneous and possess more diverse technologies, the distribution company would create additional value facilitating the interconnection of those agents and their technologies to the distribution network. In that sense a distribution platform would layer market platforms on top of the physical distribution network. The existence of these retail market platforms would generate incentives and opportunities for entrepreneurs to develop devices that can operate on that platform (e.g., vehicles, home energy management) and applications that connect the owners of those devices to other agents via the platform. For this market facilitation, the distribution platform would earn a service fee (the question whether such a platform should charge by volume (kWh) or by transaction remains an open one).

This definition of the primary roles of a distribution platform company may appear straightforward, but the scope of distribution platform that would enable it to fulfill these roles may involve the distribution platform itself being involved as a market participant. Such a role could have anticompetitive effects. For example, given the load-serving entity requirement, should the distribution platform engage in energy market transactions for backup energy generation if decentralized contracts are insufficient? To maintain system balance in the presence of diverse and intermittent energy sources like wind and solar, should the distribution platform own and control "behind-the-meter" residential solar? In both of these cases, the presence of a large, regulated buyer or seller could lead to anticompetitive vertical foreclosure.

The distribution wires network has always had economic value, but the nature of that value is changing as technology changes. The distribution utility's business can, and should, change to continue create value from this central backbone. In the early decades of the industry, the distribution network helped local electric companies increase their generation capacity utilization and reduce their average cost by supplying electricity for lighting to residences in the evening and for transportation and industrial motors during the day. The distribution network made large-scale remote generation possible, enabling electric companies to create and exploit economies of scale and scope to reduce average cost even further. For most of the 20th century, the benefits of centralized generation and the relatively low cost of maintaining the distribution grid meant that it continued to have value.

Smart grid and distributed energy technologies are changing that century-long calculus, along with the changing policy objectives that have expanded to encompass environmental quality along with the traditional social policy goals of universal electrification and low, stable prices for standard service. As distributed generation at smaller scale continues to become more economical, the potential benefits from independence, reliability, and resiliency by disconnecting from the grid become more cost-efficient.

By providing market platforms with user-friendly interfaces and open-access product definitions and data standards, the wires platform company would enable retail energy service providers to offer a range of contracts and differentiated products. Time-differentiated dynamic pricing, while not yet common, is not an untested concept, and would be easier and more potentially valuable if such a retail market platform existed.

Retail source differentiation would also be increasingly possible—not only could retailers offer renewable products (as many do today), but budget-conscious consumers could set trigger prices below which they would purchase renewably generated energy, and otherwise either purchase fossil-fuel-generated energy or have their devices change their settings autonomously to use less energy or turn off. This "green-grey mix" product differentiation becomes possible when a market platform exists that recognizes different source generation as a product characteristic, can code that dimension into the product definition, and can facilitate exchanges based on that definition. Note also how such an array of products would create more precise aggregated knowledge regarding the environmental preferences of electricity consumers; markets and price systems give consumers opportunities to make environmental choices based on their preferences, rather than the highly politicized and costly process of having administrative agencies make regulations to enforce uniform environmental policies.

Applied to electricity distribution, digital technologies have two platform-related types of effects. The first is the reduction in transaction costs that were a big part of the economic drive for vertical integration in the first place—digital technologies make distributed digital sensing, monitoring, and measurement of energy flow and system status possible in ways that were inconceivable or impossibly costly before the invention of the transistor.

The second is the ability that digital technologies create for the network firm to handle more diverse and heterogeneous types of agents in a two-sided market. Digitally enabled distributed resources are becoming increasingly economical at smaller scales, and some of these types of resources—microgrids, electric vehicles, community solar gardens—can either be producers or consumers, each having associated costs and revenues and with their identities changing depending on whether they are selling excess energy or buying it. Digital sensors and automated digital switches make it possible to automate rules for the interconnection of distributed generation, electric vehicles, microgrids, and other diverse users into the distribution grid in ways that can be mutually beneficial in a two-sided market sense. The old electro-mechanical sensors could not do that.

The burgeoning residential solar market is an example of the kind of market that can grow at the edge of such a platform (Kiesling & Silberg 2015). The residential solar market has grown substantially over the past decade, through a combination of technology, market, and policy drivers. Three-quarters of U.S. utility, commercial, and residential-scale PV systems went online between 2011 and the first half of 2013 (GTM Research 2013). Installed cost of distributed photovoltaics fell 44% between 2009 and 2014, with distributed solar installations comprising 31% of all electric power installations completed in 2013; in that same year, overall residential solar PV capacity increased 68% across the nation. California led this growth with a 161% increase in 2013 (Sherwood 2014). The residential solar market is showing how it can be competitive without vertical integration, and its growth would be facilitated by its technological and economic location at the edge of a distribution network with transparent, autonomous interconnection and competitive retail electricity markets.

If the distribution utility fears a "death spiral", it should reconsider how it creates value, and how much value it does, in fact, create. With the evolution of smart grid and distributed energy resources, but without any institutional or organizational change, the relative value of wires distribution falls. The utility is not creating as much value as it once was. How can it change its value creation? It can change by altering some aspects of its business and its role in this social-technical system. For example, distributed energy resource owners would get value out of wires distribution if by staying connected they can benefit from transactions like backup/insurance, selling their excess energy, or purchasing energy from others when the market price is lower than costs. Those potential value streams suggest that the distribution company could continue to provide value in a distributed energy resource world if the utility evolved their business model to an interconnection-facilitating retail market platform. But those ways of operating are anathema to a traditional vertically integrated utility.

A distribution platform model and competitive retail market have environmental implications. Transparent, open-access interconnection of DER would reduce transaction costs and entry barriers that currently face DER owners. A market platform layer on top of that physical interconnection, much like the transactive platforms that entrepreneurs have built on top of the Internet, enables mutually beneficial exchange and creates opportunities for sales of renewable energy. The combination of transparent interconnection and a retail market platform creates incentives for innovation at the edge of the network, including clean energy technologies, products, and services. It may be an empirical question whether such a decentralized market-based system would be more "effective" than bureaucratic, administrative energy efficiency programs ordered by regulators and implemented by regulated utilities. Decentralized systems, however, tend to be more resilient and more adaptable to change than bureaucratic, regulatory systems.

Regulation and the Platform Model

Given existing technology, fulfilling the core distribution role in the foreseeable future is likely to be a regulated function, retaining the legal entry barriers. With this core role, the primary performance objective will be a measure of reliability and how well the distribution platform delivers reliable service. The role of the regulator will be to define, monitor, and evaluate performance metrics, and to evaluate the distribution platform's estimate of its infrastructure costs to maintain and invest in the assets to enable it to perform these functions satisfactorily. The distribution platform's role as retail market platform suggests a role for the regulator in information provision, market monitoring, and consumer protection through information requirements and fraud reporting procedures.

Enabling a distribution platform business model will required the evolution of the regulatory compact from "electric service to all who request it in the utility's geographic service territory, earning the utility a normal rate of return from averaged rates" to "facilitating interconnection and transactions among all who request it in the utility's geographic service territory, earning the utility a normal rate of return".

Conclusion

If our objective is a clean and prosperous future, innovation is a crucial part of the electricity story. Recent history of digital technology indicates that an environment that allows permissionless innovation is most likely to yield the kinds of new energy-related technologies, products, and services that consumers value, that producers profit from creating, and that can reduce pollution and other uncompensated environmental costs. But electricity regulation as currently practiced is explicitly a permission-based system, and is grounded in a static theory of competition that overlooks the dynamic benefits of experimentation and learning. Changing regulatory institutions so that they prioritize those dynamic benefits, while implementing clear, transparent rules regarding safety, reliability, interconnection, and market access, will better enable this social system to foster a clean and prosperous future.

The primary driver reducing transaction costs and making decentralized coordination increasingly possible in the electricity industry is technological change. Today's digital innovations will change how we produce and consume electricity. In particular, advances in digital communication technology over the past 20 years can both improve efficiency and give customers the tools to reduce their own electricity demand. They enable remote sensing and fault detection, as well as greater intelligence capabilities within substations to deter outages or to detect them and limit their duration. From the retail consumer's perspective, such technologies create the possibility for a connected home that offers user-friendly information and access to a variety of energy services– heating and cooling, lighting, appliances, home entertainment, home security, laundry, and home health care. This transactive technology and variety of retail products and services can allow price-responsive appliances to trade in real-time retail markets, because the consumer can program his/her preferences into the trigger price settings of the appliances.

Today's stunning technological dynamism and its application to energy generation and consumption has transformative potential, due largely to the powerful decentralizing forces that digital technologies unleash. These technologies are an expression of human creativity born out of distributed experimentation. Very little of this dynamism has originated in the electricity industry, and little of this dynamism has affected how most people transact in and engage with electricity. Digital technologies now exist that consumers could use to observe and manage their electricity consumption in a more timely way than after the fact, at the end of the month, and to transact for services they value—different pricing, different fuel sources, and automating their consumption responses to changes in those. The service convergence in telecom (telephone, television, Internet) has provided consumers with opportunities to experiment with and learn the value of bundling services.

Bundling of retail electricity service with home entertainment, home security, etc., are services that have been extremely slow to develop and have not commercialized yet, due to the combination of regulatory entry barriers that restrict producers and reinforce customer inertia. All of these examples of technologies, of pricing, of bundling, are examples of stalled innovation, of foregone innovation in this space.

Smart grid technology's transaction cost reducing impacts, combined with the recent and forecast improvements in distributed generation technology, have the potential to enable decentralized exchange and network reliability to a degree unseen before in this industry. Facilitating such a transactive network would require changing regulatory frameworks to enable flexibility and adaptation to unknown and changing conditions, and to remove barriers to alternative business models, including the model of the distribution company as a facilitating, coordinating platform.

For electricity policy to focus on facilitating what is socially beneficial, regulation should emphasize clear, transparent, and just physical rules for the operation of the grid, reducing entry barriers that prevent producer and consumer experimentation and learning, and enabling a legal and technological environment in which consumers can use competition and technology to protect themselves.

By facilitating the connections of increasingly diverse, distributed users in the distribution network, a distribution platform company would lower transaction costs and interconnection costs for both the production and use of energy, which would provide opportunities and incentives for experimentation in both production and consumption. The interaction of incentives and experimentation yields innovation.

This is a substantive, meaningful sense in which the distribution wires firm can, and should, operate as a platform and think about platform strategies as the utility business model evolves. An electric distribution platform facilitates exchange in two-sided electricity and energy service markets, charging a fee for doing so. In the near term, much of that facilitation takes the form of distribution, of the transportation and delivery. As distributed resources proliferate, the platform firm must rethink how it creates value, and reaps revenues, by facilitating beneficial exchange in two-sided markets. By reducing barriers to innovation and reducing market entry barriers to distributed energy resources, a distribution platform design would align economic and environmental incentives for a clean and prosperous future.

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