Implications of Smart Grid Innovation for Organizational Models in Electricity Distribution

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1 Introduction

Economic dynamism and technological change, including smart grid technologies, have brought the electric industries and their regulators to a crossroads. Digital technologies from outside the electricity industry are prompting changes in both regulatory institutions and electric utility business models, leading to the disaggregation or unbundling of the historically vertically integrated electricity firms in some jurisdictions and not others, and simultaneously opening the door for competition with the traditional electric utility business. In particular, innovations have made residential retail competition more feasible and potentially welfare enhancing, but competitive retail markets are not the default market structure. Nor is there a single model for the role of the incumbent distribution utility in residential retail markets, where anticompetitive incumbent vertical foreclosure is a possibility (Kiesling, 2014). The increasing use of market transactions within this vertical value chain places further strain on the existing institutional structure, as exemplified by incremental market liberalization in the United States, Canada, Australia, and the European Union, and the privatization of industry in many other countries. In this complicated context, what does such dynamism imply for the role and scope of the distribution utility in the future? To what extent do these new technologies enable more efficient, more transparent, and more competitive decentralized electricity markets? This chapter grapples with these questions.

Since the beginning of commercial electric power in the 1880s, vertically integrated firms have sold electricity as a bundled good with a fixed volumetric price to consumers to compensate both for the fixed costs of wires and equipment and the variable costs of generation. Separate real-time monitoring of electric current was technologically feasible by the 1950s, but bundling and vertical integration remained the status quo for the electric utility business and regulatory environment, until technological change in generation

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precipitated the regulatory and organizational changes that brought about competitive wholesale markets. Heretofore, monopoly utilities only traded with one another to meet emergency needs, which meant that few high-voltage interconnections existed among service territories (Weiss, 1975). In the United States, meaningful institutional change at the federal level occurred with the Energy Policy Act of 1992, creating the potential for wholesale electricity markets by reducing legal entry barriers to exchange and allowing third-party generation and sales of electricity to distribution companies. This case illustrates how technological change can create potential value from organizational change; innovation changed the transactional boundary of the firm, reduced the benefits of vertical integration, and made generation unbundling possible. In a regulated industry, however, organizational structure is a function both of technology and of the regulatory institutions/framework (Kiesling, 2008). New technologies also made possible both centralized and decentralized generation, diversifying the means of energy generation and in turn providing further support for the regulatory unbundling of energy from wires. Yet, the regulation of energy and wires as a bundled good persists in many regions to this day.

This bundling and vertical integration is no longer technically necessary owing to new technologies and market structures and may, for this reason, no longer be welfare enhancing. Yet, our regulatory institutions are still tailored to an electricity network of bundled energy and distribution transactions. Institutional inertia and regulatory lock-in are obstacles to the pursuit and discovery of alternative regulatory and business models that could benefit consumers by creating new value propositions in the electricity industry. The economic and technological dynamism of the past 30 years has shown the benefits, both in cost reduction and value creation, of unbundling, particularly in generation (wholesale) but also in retail. The extent of retail unbundling's value is a function of the future defined role and scope of the distribution utility – what should be the transactional boundary of the firm, and what assets will it own, manage, and/or coordinate? In practice, unbundling is equivalent to repairing an airplane mid-flight – it requires transitioning to a new regulatory and organizational model while maintaining the ongoing commercial activity of the traditionally structured incumbent.

From a theoretical perspective, smart grid technologies bring about reductions in unit transactions cost (but may increase fixed costs, at least in the near term), a process that changes the transactional boundary of the firm. They may also lead to different pathways of development (Hughes, 1993). Organizational and institutional changes are necessary to create the welfare-enhancing potential benefits of these changes.Section 1 of this chapter outlines the technological and regulatory history of electricity distribution and the bundling of energy and wires transactions, and frames the history and its relevance today using the economics literature on transactions costs and vertical integration. Section 3 uses the literature to analyze the general effects of innovation, particularly smart grid and distributed energy technologies, on the distribution company business model. Section 4 explores the implications of smart grid and distributed energy technologies by developing a taxonomy of distribution company models and proposes consideration of a platform business model for the distribution company of the future. Section 5 concludes.

2 A Technological, Theoretical, and Regulatory History of Vertical Integration

The electricity industry's commercial origins in the nineteenth century lie in applied science, experimentation, and learning through trial and error, with decades of attempts to commercialize ultimately unsuccessful technologies such as Humphry Davy's arc lighting. Although Thomas Edison in the United States remains the most famous of the industry's pioneers, many people worked, independently and collaboratively, to turn the scientific phenomenon of electric current into a valuable everyday technology.[1]

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[1] For a useful overview of the commercial electricity industry from its origins to today, see Munson (2005) and Fox-Penner (2010), Chapters 1 and 2.

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In many ways, electric lighting was the trend-setting technology of the 1880s, complete with early adopters and customers waiting in line (temporally if not physically) for the product (not unlike today's iPhone enthusiasts). 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 (Munson, 2005, p. 20). Similarly in Chicago, early electric lighting adopters were Potter Palmer, Marshall Field, and other economic and social entrepreneurs (Platt, 1991). At the same time in Britain, Joseph Swan's incandescent light bulb and the central distribution facility at Holborn Viaduct launched the electric lighting industry in London (Engineering Timelines, 2015). Electric lighting made a social statement, and a bright and visible one at that. These wealthy early adopters gained notoriety and status from the novelty, increasing electricity's appeal to other customers, while also serving as test cases for Edison (and later others), as entrepreneurs tinkered with this new technology and improved its mass-market viability. As in other industries, early adopters pushed companies toward mass production, ultimately leading to lower costs and thus lower prices to consumers. 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.

As the industry grew, one notable objective in electricity (and its related industries, telegraph and telephone) was to secure patents. A legal patent granted to its inventor a right to exclude others from using the invention for a specified time period, while the inventor had the right to license the invention and charge a royalty for its use. The drive to patent animated the efforts of Edison and others, not just to earn a living from inventions but also for the honor and fame attached to harnessing a powerful physical phenomenon to a technology with widespread beneficial applications. 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 design and business model, and Westinghouse's (and Tesla's) alternating current (AC) system.

Direct current systems, such as Edison's, require generation relatively close to consumption, connected by a costly 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 – the transformer – allowed AC electricity to be carried long distances at high voltage using less expensive wires. 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 culmination of the war of currents was a design architecture for a particular type of electric power system built primarily on the ideas of Tesla and Westinghouse. This electro-mechanical system used AC to transmit energy on high-voltage transmission networks from large-scale central generation facilities to end users, with substations to lower the voltage to distribute the energy to end users, physical switches, and capacitors to serve as buffers to maintain reliability in a system requiring real-time balance between supply and demand and mechanical watt-hour meters to capture a running record of the total number of watt-hours consumed by the end user. Distribution networks were also designed for one-way delivery of energy from generators through substations to end users, under the assumption that power would always flow from centralized generators to customers. This system provided the technological origins of the organizational form of firms in the electricity industry.

This technology and network architecture had significant economic implications, most notably the high fixed costs associated with constructing large-scale generation facilities and transmission and distribution

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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 multiproduct natural monopoly. The defining characteristic of natural monopoly is declining average costs over the relevant range of demand; this characteristic is known as economies of scale for a single-product firm and subadditivity of cost in a multiproduct firm. The primary source of this characteristic is the high fixed cost required to build the infrastructure necessary to serve customers. Low marginal cost 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 twentieth century.[2] Thus, the neoclassical picture of this industry is one of geographically contiguous, vertically integrated electric utilities, each serving customers in their geographic footprint with a basic but high-quality undifferentiated service.

Sustaining that market structure necessitated imposing a legal entry barrier to protect the monopolist from competition and therefore 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 (Berg and Tschirhart, 1989; Sherman, 1989; Brown and Sibley, 1986). In the presence of technologies with economies of scale and scope, and subadditive costs of providing a well-defined set of complementary products and services (energy commodity, transmission and distribution service, retail service), the welfare-maximizing/cost-minimizing industry structure is a monopoly, enforced by a legal entry barrier, with zero-economic profit pricing enforced by regulation. Thus, regulation constrains the rate of return or prices, keeps prices low and stable, and limits infrastructure investment to a single, nonduplicative network. This model's framework and policy recommendations were consistent with the "public interest" theory of regulation that supported the creation of regulatory agencies in the United States in 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; Samuel Insull's role in pursuing the regulatory compact and regulation of his industry illustrates the public choice dynamic in regulation.

Static models have the benefit of being analytically clean, with clear equilibrium policy prescriptions. As technology and society evolve, however, this model and its policy prescriptions are no longer as relevant or useful because the assumptions underlying the model are no longer (or never were) accurate. In other words, static models are of limited use because they fail to account for dynamism. The prevalent assumptions include the following:

- Cost structure: diminishing long-run average cost, economies of scale, subadditivity (for a multiproduct firm);
- A well-defined set of complementary products and services (i.e., clear and unchanging market definition);
- Fixed demand, or demand increasing at a known, predictable rate and pattern;
- Full information, particularly with respect to costs;
- Fixed, constant technology;
- Regulators that can, and do, fully implement the social optimum.

The outcome in a model with these assumptions is a perennial equilibrium in which the firm earns zero-economic profit, price equals long-run average cost, and deadweight loss is minimized. In an environment of technological dynamism that changes cost structures, reduces transactions costs, and makes new product definition and differentiation possible, several of these assumptions are violated to an extent that the model no longer fits its environment. A theoretical framework for understanding when, why, and how

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[2] For an illustration of how Samuel Insull's turbogenerators created economies of scale in the early twentieth century, see Platt (1991), pp. 212–213.

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such unbundling is welfare enhancing comes from the new institutional economics literature on the theory of the firm and vertical integration.

In a standard neoclassical competitive model, with full information, no incentive alignment problems, and zero transaction costs, the existence of firms is entirely an artifact of the cost functions in the industry, of such associated issues as economies of scale and scope, and of the size of the relevant (well-defined) market. This approach undergirds the natural monopoly theory and the definition of subadditivity of costs that is the hallmark of electricity regulation.

Work in new institutional economics and organization theory demonstrates that this standard approach overlooks the incentive and governance reasons for having some transactions occur within firms and some occur in markets. Principal-agent problems, the difficulty of writing complete contracts, and other transaction costs determine the transactional boundary of the firm, and when transaction costs change, the profit-maximizing firm's boundary should change to incorporate the new trade-offs. The form and magnitude of the change in the firm's boundary is a function of the expected benefit and cost of rearranging how the transaction is realized and also of the cost of bringing about the change. As Coase (1937) and others have shown, the desire and ability to decrease transaction costs shapes vertical integration and contracting in a variety of industries (Joskow, 1988; Klein, Crawford, and Alchian, 1978; Baker, Gibbons, and Murphy, 2002; Bajari and Tadelis, 2001; Bresnahan and Levin, 2012).

Vertical integration can have both beneficial and harmful welfare effects. Vertical integration's benefits can include exploiting economies of scale and scope, cost savings, and managerial and transaction cost benefits up to a point (Klein, Crawford, and Alchian, 1978; Bresnahan and Levin, 2012). Vertical integration can harm consumers if the firm's pricing includes cross subsidies that distort demand patterns, deadweight loss if the related market is a monopoly, and deadweight loss from regulatory evasion (Brennan, 1987). It can also be a source of vertical foreclosure, in which the vertically integrated firm's participation in a downstream market with rival firms exerts an anticompetitive influence in that related market.

The risk benefits of vertical integration have been substantial in electricity, particularly in terms of reliability and product quality, and may continue to be an important factor in the organizational structure of the distribution company. Vertical integration and central generation at a distance from population centers have historically reduced physical reliability risk as well as environmental risks that are not explicitly captured in markets, such as air quality. Chao, Oren, and Wilson argue that

> Moreover, the optimal extent of vertical integration is ultimately determined by the requirements for efficient allocation of risk bearing. After restructuring, the most important determinants of the optimal degree of vertical integration concern risk management, which affects the cost of capital – the ultimate measure of financial risk – and supply reliability and resource adequacy – the ultimate measures of physical risk. (2008, p. 28)

Integrated asset ownership and regulation have essentially been a form of insurance against wholesale price volatility while also providing a business model for earning a normal rate of return on the assets used to reduce physical (outage) risk. One difference between vertical integration and contracting is the identity of risk bearer in the case of system failure. In a vertical structure with one firm owning upstream and downstream assets, that identity is likely to be clearer, and the costs of internalizing any harms arising from failures may be lower as a result. With contracting, given the inevitability of incomplete contracting, no contract will be able to stipulate all of the contingencies that might arise between the parties, and unforeseen consequences might lead to costly renegotiation or harm internalization. Damages to or failures of the electrical system harm various suppliers and utilities, and also harm electric customers and the economy at

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large. One virtue of the historical regulatory regime for electricity is the extent to which it prioritizes reliability of supply over innovation, but improvements in contracting as technologies and institutions change are reducing that relative benefit of regulation.

The value of vertical integration as insurance, however, is the opportunity cost of alternative institutional arrangements to provide similar functions. Innovations like smart grid technologies change the opportunity cost of vertical integration by creating alternative ways for consumers to protect themselves against price volatility. They also bring into question the whole concept of a uniform reliability standard, as explored in Section 4.

Transaction costs, the transactional boundary of the firm, and the feasibility of creating new markets form the framework for understanding the potential for unbundling energy from wires, a potential that smart grid technologies catalyze. Innovation, including but not exclusively technological innovation, changes the efficient transactional boundary of the firm because it affects the transactions costs, economies of scale, and economies of scope that make vertical integration a profitable organizational structure. These technological changes have created the opportunity to change transaction costs in the industry, thereby creating opportunities to do two dynamic things: change the boundary of the firm in accordance with the change in transaction costs and create new markets where they previously failed to exist because of transaction costs.

However, the organizational structure of firms in the industry is also a function of the regulatory environment. Technological change has created the *potential* for shifts of the transactional boundary of the firm and for market creation, but regulatory institutions reinforce the use of antiquated or suboptimal, but *known and familiar*, technology. These institutions fail to integrate new technologies adequately into regulatory planning. The investment in existing electro-mechanical technology that is a sunk cost, yet creates an information monopoly for the regulated utility, reinforces an inertial lock-in, and reduces the incentives to develop technology feedback effects.

What began as a patent-driven, electro-mechanical, vertically integrated industry has experienced technological change that induced unbundling of generation and liberalization of wholesale markets. When technological change reduces transactions costs it changes the transactional boundary of the firm and reduces the costs of creating new markets, but economic regulation can rigidify organizational evolution as economic agents adapt to the changes. The evolution of policy objectives to include environmental quality complicates this process further. This historical overview suggests that smart grid and distributed energy technologies will create forces for organizational and institutional change that are likely to make retail unbundling welfare enhancing and to change the transactional boundary and the business model of regulated distribution utilities to more adequately integrate these and future technologies into the electricity system.

This vertically integrated, government-owned or regulated industry has not existed in a vacuum. Exogenous technological change has placed pressure on the business model and institutional framework and has induced some change, most notably in liberalizing wholesale power markets and unbundling generation in the 1990s–2000s, and the subsequent institutional work to design rules to allow more market integration, particularly in the European Union and United States. Today, smart grid and distributed generation technologies are shifting the transactional boundary of the firm at the margin, placing pressure on the business models and institutional frameworks of the industry again.

Large, centralized generators integrated with transmission and distribution systems realized significantly lower operating costs than smaller generators for most of the past century. Nonetheless, several factors have facilitated the shift to unbundling and competition over the years as the economies of scale in large central generation became fully realized in the 1970s (Christensen and Greene, 1976). Technological advances have led to more efficient gas-fired generators, and high-voltage transmission lines providing transport of electricity over greater distances consequently give consumers more choices in power suppliers. Exogenous technological changes such as the combined-cycle gas turbine changed the economies of scale and scope

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driving the traditional business model, changing both the economics of generation and the economics of the vertically integrated firm.

Some countries privatized government-owned electricity industries, leading to private, independent generation firms that operate across multiple countries (e.g., in the European Union). In the United States, as a result of the Public Utilities Regulatory Policies Act of 1978 (PURPA), the rise of generators using renewable energy sources showed that there were reliable sources of power other than large-scale central generation owned by a vertically integrated firm (Bosselman, Rossi, and Weaver, 2000, p. 718). Other countries, such as Australia and Canada, have introduced wholesale and retail market competition to varying degrees on a regional level, while the four countries in the Scandinavian Nord Pool market have restructured to allow unbundling and retail market competition (International Energy Agency/OECD, 2005).

In the EU member countries, the history of private, for-profit electricity firms is more recent – in countries such as the United Kingdom and Germany, private entrepreneurs started the industry, but in the twentieth century, there and in other EU member countries, the electricity industry was nationalized, only to be privatized in the 1990s through government reform and the establishment of post-Soviet governments in former Soviet countries. One consequence of this nationalization was that the ownership of assets, particularly generation assets, was more concentrated and centralized coming into restructuring than has been the case in regional markets in the United States. This contrast is also due in part to regulatory federalism in the United States, combined with the prevalence of private ownership in the industry.

A set of European Commission-led reforms over the past decade established a clearly delineated path for electricity restructuring in the European Union, which has resulted in broad wholesale market liberalization and more extensive retail competition than in the United States in some respects (Pollitt, 2009; Florence School of Regulation, 2013). In the mid-2000s, the European Commission and other observers found that insufficient unbundling was indeed a barrier to retail competition in many markets (Cornwall, 2008, p. 129); since then, some unbundling and expansion of retail competition has occurred in more member states (e.g., Belgium). Thus, in the European Union, some parts of South America and North America, and Australia, substantial unbundling has occurred, although patterns and experiences differ.

The EU challenge in this context is to achieve the benefits of unbundling, including the potential new value creation from new, differentiated products and services that may accompany unbundling and more decentralized markets that SG technologies make possible, while still negotiating integration, physical coordination, and market design for an EU-wide wholesale market in which nationally based firms own wire networks in various structures. In both the European Union and elsewhere, the development of smart grid technologies based on general-purpose digital innovations of the past 30 years is accelerating the commercial and policy attention to such institutional issues.

3 Smart Grid Innovation and the Economics of Vertical Integration

As a digital communication network overlay on the electro-mechanical wires network, smart grid technology enables and reduces the cost of two-way communication. In electricity as in other industries, digital technology makes two-way communication possible and easy, as well as using that communication capability to automate individual actions. The proliferation of communication technology has made engaging in transactions easier and cheaper. By changing transaction costs and economies of scale and scope, the technology changes the transactional boundary of the firm and reduces the economic impetus for vertical integration.

Personal banking provides a useful analogy. Two innovations have transformed personal banking: the ATM and the Internet. Automation and online banking have largely replaced brick and mortar banking, or banking by phone. Transactions are easier, quicker, and cheaper for customers and banks. Furthermore, customers

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can use this technology to automate actions, such as scheduling recurring bill payments, or establishing trigger rules for alerts about accounts. Other transactions become more convenient, such as paying back a friend for dinner using a bank's online quick-pay service, or third-party payment technologies such as Venmo and Paypal. Digital communication technology enables banking any time, from anywhere, secured with two-factor authentication and device identification; it also enables payment without any centralized authentication at all, using technologies such as Bitcoin built on a blockchain technology platform. The value creation due to this transactive capability has been enormous and has largely been in the form of consumer surplus.

Banking is just one example; think about online shopping, eBay, and all of the other economic transactions in which people engage using the Internet. The implications of this transactive capability have been enormous; it has reshaped markets, firms, and consumer expectations. Markets are increasingly global and competitive, and we can engage in transactions with people on the other side of the world. However, the most important implication of transactiveness for the electric power industry is the effect on firms, through the effect of innovation on transactions costs.

From the consumer's perspective, the implications of a transactive smart grid can be profound. How can the online banking experience translate to energy transactions? Imagine what that kind of transactive capability would be like with respect to energy use. Capabilities now possible include online home energy management, remote access, the ability to automate electricity consumption decisions by time or price or fuel source, the array of new products and services that could make use of this transactive functionality, and the potential to offer this range of products and services via competing retailers to the diverse consumers in the electric power network. Large industrial and commercial consumers already have such capability, but as technology prices have fallen and entrepreneurs have developed new products and services, a transactive smart grid brings this functionality into the home, creating potential value for consumers, and for the producers and entrepreneurs who provide them the products and services they value.

Smart grid technology makes a more decentralized network structure possible. It also makes the (human and technology) participants in the network more heterogeneous, particularly in the nature and scale of generation and consumption technologies that can now be interconnected. Distributed generation, renewables, and electric vehicles (EVs) provide one illustration; the nature of the generation and use patterns of these technologies differs meaningfully from the traditional central generation technologies, and digital technologies reduce the cost and automate the effort of interconnecting them while maintaining reliability/security of supply.

An even deeper heterogeneity becomes possible due to digital technologies: the human agents themselves can change roles, assuming different roles depending on market conditions. Take the example of an EV owner. The EV does not just consume energy to provide transportation; it also acts as a storage device. If a market exists into which that EV owner can offer to sell a certain amount of energy in a certain time period, that agent in the network can be a seller, not just a buyer, of energy. These changing roles, and the ability to have different roles at different times, have implications for asset utilization, capacity factors, and economic and energy efficiency. Engaging in regulatory design or market design without taking account of this potential opportunity for value creation could lead to substantial unrealized gains, both for individuals and for the system as a whole. Lowered transaction costs and more decentralized networks permit small-scale value creation and experimentation at edges of the network. Unfortunately, twentieth century assumptions regarding the nature of electricity technology and its regulation stifle the development of these networks.

Despite the decentralizing benefits of innovation, the risk-allocation benefits of vertical integration are still relevant, as is the cost of modernizing the distribution system to enable two-way energy flow along with information flow. However, smart grid makes retail unbundling even more preferable than it had been previously, because the reduction in transactions costs increases the feasibility and potential value of decentralized contracts to coordinate and organize economic activity. By enabling distributed innovation at the

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distribution edge, it may also create new ways to manage both financial and physical risk and allow for transacting over risk that may make vertical integration a less valuable organizational response to risk. It also enables purely financial parties to enter the market, such as private equity firms that are participating in the UK market. Smart grid technologies also make distributed physical balancing and control feasible where centralized control was the only alternative before. Both the interconnection and network edge technologies and the distribution system technologies better enable distributed control to achieve network reliability. One example of such use is transactive control.

Transactive control uses smart grid technology to communicate incentive and feedback signals to distributed agents in the electric power network (Pacific Northwest National Laboratory, 2011). For example, communicating a real-time price signals to end users the opportunity cost of their choice to consume that energy at that time, and it informs their incentives. Once an end user has made a decision, probably by entering a trigger price and automating their device responses to the price, the decision is communicated back autonomously to other users and provides feedback. If the device was programmed not to buy energy at that price, information on its action feeds back through the retail market and could have several economic and physical consequences – a lower market-clearing price, balancing in the distribution system, and enhanced reliability achieved through decentralized coordination. These wider system benefits mean that a transactive design can be welfare enhancing even for those customers who choose a more traditional fixed price or time of use electricity contract.

Transactive control enables individual agents to be active decision-makers through the autonomous participation of their devices in communicating setting changes in response to changes in attributes such as price or renewable energy availability. As a method of distributed control, it also facilitates the interconnection of distributed resources, from utility-scale solar down to the EV at a home, in a way that can be both economically beneficial to producer and consumer and systemically beneficial through autonomous control and distributed storage. Both past research (Chassin and Kiesling, 2008) and the current Pacific Northwest Smart Grid Demonstration Project (www.pnwsmartgrid.org) suggest that transactive control can deliver both individual and system benefits. It may also enable regulatory and organizational change that would be economically and environmentally beneficial.

4 Asset Ownership and the Future of the Regulated Electric Utility

The literature on vertical integration and the potential value creation from smart grid technologies suggests that the scope, role, and nature of the distribution company are likely to change. What wires-related functions should distribution companies play in the system more generally, given both the known and the unforeseeable changes associated with smart grid and distributed generation technologies into the future? Given the increasing economic and technological heterogeneity and complexity emerging in the industry, there is likely no “one size fits all” distribution company ownership configuration. Industry structure and market design have been, and will continue to be, a synthetic consequence of the interaction of emergent outcomes and deliberate regulatory design.

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

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The challenge comes, however, in assessing what transactions and what ownership rights are consistent with even this thin business model. Does the distribution company's reliability requirement justify its ownership of backup generation, or can they acquire that assurance through contract? In most cases, contract will suffice. However, a harder example is behind-the-meter residential solar – is there a reliability justification for distribution company ownership of those assets? Traditional vertically integrated firms have succeeded in making that argument in states such as Arizona, despite the fact that in other states, residential solar is a vibrant, independent, competitive market.

One benefit of unbundling retail and restricting the distribution company to be a wires company, is the very real possibility of anticompetitive vertical foreclosure.[3] When incumbents can exercise vertical market power in nominally competitive downstream markets, that market power can act as an entry barrier. Monopolists are rarely anticompetitive by entering a new, related market. Instead, the problem stems from monopolies failing to sacrifice market share or to exit when innovation and dynamism become relevant competitors, and regulatory institutions likewise fail to facilitate the diminution of the monopoly. Failure to exit differs from barrier to entry because the anticompetitive effects arise largely from incumbency and consumer inertia. Any regulatory restructuring should take into account this inertia and should eliminate policies such as incumbent default service that embed entry barriers. Moreover, retail competition is the market design and process best able to facilitate the economic experimentation that is most likely to lead to value creation, increased consumer surplus, and increased total welfare, which are the objectives of sound competition policy (Kiesling, 2014).

In the various possible ownership configurations for the distribution company of the future, the fundamental challenging question is what functions and transactions they will perform in addition to those associated with distribution wires ownership. These functions fall into two categories: retail service functions and environmental policy target functions. Does the distribution company provide retail service, even in a competitive retail market, or should it be "quarantined" from the retail market to reduce vertical foreclosure? Does it own assets behind the meter, or does its footprint stop at the meter? How are electricity prices set? What choices do consumers have regarding rate structures? Does the distribution company own renewables distributed resources and/or commit to "programs" such as energy efficiency to meet environmental policy targets (as in the solar example discussed above)? How does it encourage efficient use of the grid, both for economic and environmental reasons?

Framing the organizational structure question as a life-cycle model of integration raises the question of the current stage of electricity distribution in its integration life cycle. In the traditional vertically integrated ownership structure, the regulated utility owned all generation assets, driven largely by capital requirements and high fixed costs incurred in exploiting economies of scale. Recent innovations, however, change the scale and the nature of generation, the cost of coordinating heterogeneous distributed generation in the network, how end users can observe and automate their energy use choices, and the costs of establishing retail markets and exchange. These new technologies open opportunities for decentralized, distributed ownership structures, departing from the vertically integrated utility structure and moving toward reliance on transactions and contract. They also open the issue of who owns the distribution company – is it investor-owned, owned by a joint venture of independent retailers (Boffa and Kiesling, 2015), or some other structure?

The unbundling that has occurred since the 1990s has led to independent generators, with regulated utilities owning transmission and/or distribution wires networks. Some jurisdictions also have retail competition, with the distribution utility active in that market as a supplier, or precluded from it to prevent anticompetitive vertical foreclosure, depending on the jurisdiction. Smart grid and distributed energy innovations reconfigure generation scale and location in the network. Given current and unknown future technological change, and in light of the wires-related functions and transactions laid out above, should distribution utilities own

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[3] In the European Union, thus far this argument has been most salient regarding transmission rather than distribution (Pollitt, 2008).

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assets and transact directly on their own behalf, manage transactions on behalf of others, or coordinate the transactions of independent economic agents? Simply raising that question yields three categories of business models: ownership, management, and coordination.

Ownership/Vertical Integration. The distribution company directly engages in energy-related transactions themselves, as market participants. The firm bears financial risk and outage risk fully, but uses ownership structure to hedge fuel price risk; however, note that changes in the fuel portfolio composition as the potential generation portfolio gets more heterogeneous and more distributed and smaller scale reduces that risk. Ownership also means ability to add assets to rate base, maintaining the status quo revenue structure, for as long as those assets do actually continue to generate revenue. In many respects, this model corresponds to Fox-Penner's energy services utility (Fox-Penner, 2010, Chapter 13).

Economies of scope, particularly with respect to the utility's reliability/supply security and energy efficiency mandates and the management of risk and fuel price volatility, provide the best argument for this model. The transaction cost reductions arising from smart grid innovations also change economies of scope and may increase transactions also change economies of scope and may increase the opportunity cost of choosing to retain vertical integration instead of other alternatives that may be cheaper or more convenient.

Manage rather than Own. In this model, the distribution utility uses the automation and communication capabilities of smart grid technologies to manage transactions on behalf of agents in electricity markets; this management function can include some ownership of assets for reliability purposes. The distribution company, responsible for reliability/supply security, can engage in some energy transactions to procure generation as needed to meet reliability and energy efficiency objectives. In some respects, this role corresponds to the existing context in US states that have net metering rules stipulating the administrative prices at which customers will be paid for any excess energy they generate that they put on to the distribution network. The utility determines DG interconnection standards and can use smart grid technology to automate acceptance of energy on the network for reliability and balancing purposes. The real difference between ownership and management is retail unbundling, but the DSO retains ownership and market participation with respect to reliability-related assets. This model corresponds to Fox-Penner's smart integrator (Fox-Penner, 2010, Chapter 12) and is similar to a system operator model.

A political economy issue in this management model is defining what constitutes a reliability-related asset. The distribution company has a revenue incentive to expand that category, and regulators may or may not have a political incentive to accept such a broad definition. In a case of regulatory capture, the distribution company will be able to argue successfully to expand ownership beyond what is required, with waste and inefficiency as a result. Another cost of such incomplete unbundling is the possibility that the DSO's market participation can create anticompetitive vertical foreclosure, as discussed above.

Coordinate. In this category of models, the distribution company is not a wholesale or retail market participant, but is instead a facilitator of the transactions of independent, distributed agents in the electric network. Coordinate rather than own or manage means that nonwires assets are not in rate base, so regulators must consider performance-based, service-defined methods of compensation for the regulated utility. The distribution company coordinates among the agents distributed in the network, and as the activities of the agents are most likely to be transactions, this coordination takes the form of providing market infrastructure. The distribution company contracts with agents to provide wires-related and reliability-related services, recognizing and allowing for the distributed transactions of economic agents to ensure reliability themselves, without as much of a reliability requirement or reserve requirement as currently exists. For example, if an open retail energy market exists and an EV owner can submit an offer to sell 1 kWh in a given hour and it is accepted, those parties have mutually benefited. By coordinating the exchange, the distribution company's market platform uses digital technology to enable them to create value. The relevant reliability issue is having the distribution company able to see the transactions so they can charge the appropriate (open access) wires charge for the transaction and maintain balance in the physical system. Note that smart grid technology

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enables the distribution company to engage in this monitoring and wires charge calculation autonomously. The distribution company also provides information to enable self-coordination among agents and requires transaction reporting to enable them to have information on system balancing, but still maintains system balance and reliability through these decentralized means. In other words, in this model, the distribution utility becomes a *platform service provider*.[4]

Platform firms connect distinct users in a network. A digital platform firm, such as 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, telephone companies, gas companies, and electric companies started as vertically integrated firms. Rail network owners were vertically integrated upstream into train ownership and transportation provision, and electric utilities were integrated upstream into generation. In network infrastructure industries, the platform is physical, and firms bundled the network service into their offering. However, these network infrastructure industries have not been seen or thought of as platforms in the sense that we are coming to understand as such firms and industries emerge, because of the economic benefit and the historical path dependence of the vertical integration.

Consider a business model in which an unbundled wires company facilitates coordination among the heterogeneous agents in an electric power network. The agents may include, for example, large generators, commercial microgrid owners, industrial facilities with their own combined heat and power installations, residential customers with EVs and rooftop solar, and utility- or distribution-scale energy storage. As smart grid and distributed generation technologies evolve, these agents may change in unforeseen ways. A wires platform company could provide three types of beneficial coordination between agents on the network: economic coordination, physical/reliability coordination, and information provision and in addition can help the entire network in aggregate meet environmental and other policy mandates.

Economic coordination means reducing the costs of agents finding each other who might be able to engage in mutually beneficial transactions and can also involve standardizing and automating contracts and trades. Consider the analogy of financial markets, in which a firm serves as a market platform where potential buyers and sellers can meet and make bids and offers for exchange and charges a fee or commission for facilitating the exchange. A wires platform company could act as a retail market platform, in which suppliers submit offers to sell energy and buyers submit bids to purchase. The buyers could be individual agents, such as a homeowner's thermostat bidding directly into the market, or bids from individual agents submitted by retail energy service providers with whom homeowners have contracted for energy management services. A retail market platform would likely provide a range of markets, including hourly day ahead, hourly spot, 15-min spot, balancing, and ancillary services such as reactive power, mirroring existing wholesale market designs where desirable.

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 (assuming $p_R > p_F$), 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-gray mix" product differentiation becomes possible when a market platform exists, which recognized different source generation as a product characteristic, can code that dimension into the

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[4] New York State's Reforming the Energy Vision (REV) process, currently under development, is a regulatory proceeding that is constructing a model of a platform service provider (New York State Public Service Commission, 2014).

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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.

A key institutional design question will be how the various agents pay for the platform services, particularly in the case where only a few parties are using them and the pricing must reflect some allocation of fixed costs. Such platform pricing questions have raised antitrust and competition policy questions, ranging from Microsoft's web browser bundling to the "swipe fees" that credit card companies charge to merchants (Armstrong, 2006), so this question will continue to be high priority.

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). However, smart grid technologies and their transactive nature mean that, to each individual agent in the network, reliability and its value can vary. Reliability need not be uniform across all agents, or across all uses of electricity; indeed, the economic value of reliability differs across uses, and market processes enable consumers to benefit while their market choices communicate the different values they place on reliability. Using the automation and transactive capabilities of the technology to define different types of reliability as differentiated products may be value enhancing and attractive to some consumers (Giberson and Kiesling, 2007). Consider a homeowner who has one room in which she wants highly reliable service and is willing to pay for it (say, the kitchen, or the computer room) and is willing to accept less reliable service at a lower price for other rooms in the house. Smart grid technology makes it feasible for an energy retailer to design and offer such a contract, and for a wires platform company to implement it. As a result, marginal energy curtailment practices such as demand response could create greater and deeper cuts to electricity demand as needed, if and only if network participants are given the opportunity to express a willingness to pay or be compensated for reliability. The combination of technology and contract could also make distributed generation and demand response from some agents dispatchable that were not before. Digital automation and switching can make a commitment to supply energy or to reduce consumption physically firm, a capability that did not exist in the electro-mechanical network. Once decentralized dispatchability is technologically feasible, retailers can make it contractible and can offer different prices depending on whether or not the resource under contract is dispatchable. One challenge will be pricing the regulated infrastructure services in an open, transparent, and nondiscriminatory way that enables entry, experimentation, and innovation at the distribution edge.

The scope, role, and nature of the distribution company will change in the foreseeable future, driven by the effects of innovation on the economics of vertical integration. Precise organizational models will vary by context and region, but in all cases policy makers will have to consider the relative merits of the distribution company's role as integrated utility, network manager, or coordinating platform provider.

5 Conclusions

From its commercial origins, the electricity industry's organizational structure and regulatory institutions have been shaped by its technologies. As digital entrepreneurs create smart grid (and distributed energy) technologies, industry members and policy makers will have to consider the benefits of a more distributed, decentralized architecture that smart grid enables, and the associated implications for the business model of the distribution company.

The transaction cost reductions arising from digital communication technology shift the margin at which it is profitable to organize transactions within a firm instead of through markets, changing the margin at

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which vertical integration is a better organizational structure than contracting. If transacting in markets is now cheaper, then transactive activity should shift at the margin from within-firm to between-firm, and firm boundaries should change. Vertically integrated firms exist for several reasons, and transaction costs provide only one reason, but lower transaction costs due to smart grid technologies will contribute quickly to the increasingly stand-alone capability of the retail portions of the electricity supply chain. Smart grid technologies reinforce existing arguments for retail unbundling.

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.

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