The Connected Home and an Electricity-Market Platform for the Twenty-First Century

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It's the start of a new week. Monday morning, the alarm that wakes you up is a gentle, increasingly glowing full-spectrum LED light timed to wake you up refreshed and on schedule and connected to sensors embedded in your pillow that determine where you are in your sleep cycle. As you stand up, the motion sensor in your bedroom alerts the vacuum-packed coffee bean storage in the kitchen to grind the beans and brew your first cup of coffee just the way you like it. You press the shower button, and the on-demand electric water heater gives you a shower at the precise temperature you prefer, a setting that you can change seasonally or leave alone, as you prefer. The coffee maker, water heater, and shower may also have used Bayesian learning to record the patterns of your morning routine without the need for any explicit programming on your part. The devices learn your patterns and just work, yielding a quality of life that was not possible before.

You may also choose to time the water heating (and perhaps your shower, if you have a flexible schedule) based on the price you pay for electricity; you have programmed in your trigger prices in your home-management system, and if the price forecast for your usual shower time is higher than the trigger price, the water

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heater can preheat water for your shower, saving you money with no loss of comfort or convenience. The same functionality exists in your home's heating and cooling system as well as in the major energy-consuming and energy-producing appliances and devices in your home.

You have contracted with a home-services retailer to provide you with a bundled network service for communication, entertainment, home security, and energy, and you have choice among several retailers. The services for which you contract and the way that you pay for those services will be diverse, and you can customize your services as much or as little as you prefer.

The next fifty years will involve increasing human interaction with digital technology as the Internet of Things grows and more devices have more embedded intelligence and automation capabilities. The alarm clock starting the coffee maker is a colorful illustration of the extent and depth to which the Internet of Things will change how individuals interact with the physical environment, and with each other. Many of these changes will occur in the home, intersecting with the consumption and increasingly with the production of electricity.

Some of these capabilities already exist and are not fifty years in the future. In-home technologies such as the Nest thermostat use Bayesian learning to figure out habitation patterns and adjust home temperatures accordingly. Connecting the Nest thermostat with the Nest smoke/carbon monoxide detector and remote-control LED lightbulbs enables improved safety and home security, and temperature and lighting can be automated and adjusted using a mobile-device app. Whirlpool has created a line of Whirlpool Smart laundry appliances and an accompanying mobile-device app to control the timing of laundry cycles and their energy use. Not all of these innovations have demonstrated value to consumers yet, but they may.

Innovation aligning economic and environmental incentives also comes from the evolution of the connected home. Imagine, for example, customizing the 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. Technologies already exist to make some of these capabilities possible, and innovation is bringing about more of them.

In all aspects of daily life, digital technologies have reduced transaction costs, enabled deeper and richer decentralized exchange (think of automatic teller machines, online commerce, Uber, and Airbnb as examples), and fostered a greater ability to automate routine interactions (e.g., Amazon's Subscribe and Save feature). In the built environment, digital technologies and their powerful decentralizing and transaction-cost-reducing forces align economic and environmental values, enabling individuals to save money and increase environmental quality by using digital technologies to optimize their energy consumption and production.

These economic and environmental benefits arise in part out of the ability to automate actions and transactions. The British philosopher Alfred North Whitehead famously observed that "[c]ivilization advances by extending the number of important operations which we can perform without thinking of them" (1911, 46), and F. A. Hayek observed similarly, "The more civilized we become, the more relatively ignorant must each individual be of the facts on which the working of his civilization depends" (1960, 26).

Looking into the next fifty years of electricity and technology involves several deep unknowns. In 2015, the long-awaited and much-vaunted development of more economical energy-storage technologies is accelerating. Combined with innovation in distributed generation, storage innovation is likely to be a substantial disruptor that will change electricity consumption and production over the next five decades. Both solar photovoltaic technologies and electric vehicle technologies have in the past five years improved in energy efficiency and decreased production costs, although based on cost alone they cannot yet match mature fossil-fuel technologies.

Although Vaclav Smil (2015) is correct that there is no Moore's Law for energy technologies as exists for communication technologies, further research and innovation in distributed energy and storage will change the scale at which electricity can be generated economically. The last time this happened was in the late 1980s, when the combined-cycle gas turbine undercut the monolithic economies of scale in generation and prompted regulatory change to allow competitive wholesale markets and spur the unbundling of generation from the vertically integrated, regulated utility in several states.

These innovations change not just the economies of scale in generation but also the nature of the transactions themselves. Distributed resources and storage make the residential consumer both consumer and producer, which means that a more decentralized retail market is possible rather than the traditional monolithic linear supply chain from the vertically integrated firm to end-use consumers. The potential for a highly decentralized retail market for electricity is amplified further by digital smart-grid technologies, which make interconnection easier, more automated, and less likely to create imbalances and outages in the distribution grid. Digital smart-grid technologies also enable the interconnection of increasingly heterogeneous devices across a network of homes and other buildings. These buildings and devices are owned and operated by increasingly heterogeneous types and sizes of agents. A homeowner can own an electric vehicle or a residential rooftop solar, enabling both consumption and generation of electricity. Microgrids can connect a neighborhood of individuals and technologies capable of consuming or generating or both, at both large and small scales.

These technological innovations also change the potential for another wave of competitive markets and unbundling, this time in competitive retail markets and the unbundling of retail service from the distribution-wires network, which at least in the near term is likely to retain its economies of scale. The markets, business models, and regulatory institutions that will emerge are also unknown; they will depend on the nature and pace of innovation, the political economy of unwinding a regulated industry heavily invested in the status quo, and the extent to which the culture of consumers, producers, and regulators embraces an attitude of permissionless innovation (Thierer 2014).

One final unknown is the extent to which these innovations will induce residential electricity consumers to use distributed resources and storage for self-sufficiency and thus go "off-grid" rather than stay connected to the distribution grid. Consumers leaving the grid reduces revenue to the regulated wires owner. Whether regulators and utilities can bring about changes to make the distribution grid connection valuable in an environment with distributed resources will be a significant challenge in the next two decades. Transitioning into a role as the distribution grid operator and market platform provider (and not a market participant) would enable the wires company to earn revenue by facilitating mutually beneficial transactions and by providing transaction fulfillment through coordination of multidirectional energy flows.

In electricity, as in other industries, digital communication technology makes it possible and easy to have two-way communication and to use that communication capability to automate individual actions. As we have seen throughout society, the proliferation of communication technology makes it easier and cheaper to engage in transactions. The implications for the electric power network are a rich transactional environment, a market platform, and a network connecting producers and consumers who contract and negotiate their mutual exchange of value (product, service) for value (payment). A smart grid is a transactive grid.

Digital technologies can make the electric power network transactive over the next fifty years. These technologies, though, are necessary but not sufficient—an economically (and environmentally) sustainable electric power network in 2065 will also require institutional change. Except for municipal water, electricity remains the most heavily economically regulated of the infrastructure industries, and this economic regulation has to this point focused on universal electrification and low, stable prices for a standard commodity service. Regulation creates entry barriers in retail electricity markets in most states in the United States, and in the states that do have retail markets for residential customers, some persistent features of regulation have entrenched entry barriers and incumbent vertical market power (Kiesling 2014). The traditional focus of regulation on investment in generation and wires assets means that both regulators and regulated utilities have a significant status quo bias.

Retail entry barriers and status quo bias mean barriers to innovation. Market entry remains the most potent process for creativity and new value creation in the form of technological change and product differentiation. Regulatory institutions are not adaptive and generally do not deal well with change, in particular the effects of technological change. They arose in and are conditioned to a specific social-technological context that has been changing over the past two decades due to the decentralizing forces of digital technology. The policy challenges and objectives present in the twentieth century have receded and been reprioritized along with new policy challenges: providing incentives to innovate and adopt new technologies, providing the type of customer choice and decentralized decision-making capabilities that consumers experience in nearly all other aspects of their lives, managing the environmental consequences of electricity consumption, and maintaining reliable service in the face of consistent, pervasive change.

If retail regulatory institutions do not allow firms the freedom to enter or consumers the freedom to choose how much price risk to bear and what price signals to receive, then they fail to deliver on the dynamic value-creating potential of the smart grid as a transactive market platform that enables the connected homes of the future to be assets for exchange.

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