PROMOTING INNOVATION IN THE ELECTRICITY INDUSTRY[1]

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Smart metering can bring significant benefits to the electricity markets by allowing customers to reduce demand or increase supply when generation capacity is temporarily scarce. To reap the full efficiency and environmental benefits of this technology, regulators must allow price volatility and free entry into the market. The efficiency gains are enormous as both demand and supply will be affected by both temporary and longer-lasting price changes. Experiments have shown the value of this approach.

Keywords: Utility regulation, electricity markets, smart metering.

Technology and institutional design

How does technological change affect the role of economic regulation in retail electricity markets? I will offer some observations and research from a US perspective that I believe generalise to other settings as well. I also hope to challenge some current thinking about the potential retail value propositions involving electricity, and the role of regulation in retail markets in the presence of technological change. In particular, digital communication technology has made rich, vibrant, customer-oriented innovation possible. Some examples of such consumer-focused innovation include appliances and devices that can respond autonomously to changes in electricity prices; electric vehicles that can be programmed to charge when electricity prices fall below a trigger price set by the owner and serve as an energy storage device as well as a vehicle; or home energy management systems that enable the homeowner to set appliances to power down if the electricity they are using would be bought on the wholesale market during an hour when renewable power was not available (the green–grey portfolio mix). The technologies to bring these products and services to retail customers exist: the regulatory institutions that enable it do not.

These topics fall under the general category of smart grid. The buzz around the idea of smart grid is palpable: old companies such as General Electric and new companies such as Google are changing their business models to incorporate more smart grid activities and products, entrepreneurs are exploring new products and services at unprecedented rates, and federal legislation supports smart grid investments and has directed $40 billion of taxpayer funding to smart grid investments.

Defining 'smart grid' requires thinking about the subject from two different directions simultaneously – its technologies and its functionalities. Technologically, a smart grid is a digital communication overlay and integration into the electric power network. This communication technology includes:

- digital switching networks;
- remote sensing and monitoring in wires and in transformers;
- fault detection in wires and in transformers;
- devices for automated fault repair; and
- intelligent end-use devices in homes, stores, office buildings, garages and factories.

These various smart grid technologies enable a variety of functionalities in the electric power network, such as:

- transactive co-ordination of the system (many of the following functionalities contribute to this co-ordination);
- distributed resource interconnection, including renewable generation and electric vehicles;
- the ability of a resource/agent to be either a producer or consumer of electricity, or both;

- demand response to dynamic pricing, and automation of that response;
- the ability of an agent to program end-use devices to respond autonomously to price signals; and
- distribution system automation by the wires company, leading to better service reliability.

The integration of these technologies into the electric power network will embed distributed intelligence in the physical systems that the network comprises. When I refer to the grid or the electric power network I am including distributed human agents (and their private knowledge–preferences–intelligence) in the definition of the network, not just the physical assets.

The potential ways that smart grid capabilities can create value are large, and they transcend the traditional utility-provided, generic electricity generation and delivery value proposition. By enabling better, and more decentralised, co-ordination of electricity supply and demand, smart grid functionalities contribute to the optimisation of resource use in the entire electricity system. This optimisation has both economic (cost reduction) and environmental (reduced resource use, reduced emissions) implications. Note, though, that the connection between distributed intelligence and decentralised co-ordination allows these economic and environmental benefits to align and converge. One example of this convergence is how dynamic retail pricing induces consumers to shift consumption away from expensive peak hours, which leads to a reduced need for expensive infrastructure investment that is built to meet peaks and then sits idle for 95% of the year: avoiding that investment saves costs and saves resources.

Paradigm shift

These dramatic and exciting technological changes are on the verge of creating a paradigm shift in this industry. Historically vertically integrated and regulated, the electric power industry in the USA was designed for centralised physical and economic control, both for operational reasons and for economic efficiency and equity reasons. Reliability and system balance have always been the paramount policy objective, and from an economic perspective, the principal illuminating regulation has been a concept of ‘the public interest’ used to control the exercise of market power. Under the public interest theory of regulation, creating monopoly electric utilities and regulating the rates of return they earned minimised the deadweight loss associated with monopoly, while at the same time eliminating the competition that drove market prices below long-run average cost under free entry. This argument is based on neoclassical natural monopoly theory, in which the cost structure of the firms in the industry relative to the size of the market would ultimately lead to having a single firm operate in that market.

These regulatory and legal concepts are generally static, and do not adapt well to unforeseen and changing conditions, including economic dynamism and technological change. Consumer-focused, end-use innovation creates the opportunity to access consumer intelligence at the edge of the electric power network, enabling distributed, individual agents to co-ordinate their plans and actions transactively. Through that process we achieve what is known in complexity science as emergent order through decentralised co-ordination. However, regulatory institutions that are designed for centralised control, and the economic interests of incumbents who profit from that state of affairs, present barriers to achieving this decentralised co-ordination.

Moreover, regulatory policy objectives in electricity are increasingly in tension. Reliability of service and of the physical network is paramount, and rightly so. Another high-priority objective for the past century has been affordability and predictability, in the form of low, stable retail prices that insure all retail customers against price volatility. Intended as a bulwark against monopoly, this policy also stifles both the communication of cost information to consumers and the communication of consumer preferences back all the way through the value chain to generators. Consequently, to the extent that consumer preferences and production costs vary from average benefit and average cost over time, these regulated, averaged prices lead to inefficient outcomes with distorted resource allocation.[2]

Over the past 20 years, though, the complexity of our policy objectives has increased as our interest has grown in reducing the environmental impacts of energy use, and in decreasing energy use and improving energy efficiency. Low, fixed (and still regulated in most of the USA) retail prices are in direct tension with consumer empowerment to reduce the environmental impacts of energy use. Fixed, averaged, regulated retail prices send no signal, and give no incentive, about the relative economic or environmental value of changing consumption at a particular time. The current context of increasing capital costs and supply constraints compounds that tension.

These observations prompt the question: are low, stable retail prices that do not reflect underlying cost fluctuations actually in the public interest, particularly in light of innovations in end-use digital technology? Is our historical policy focus on low, stable prices still serving the public interest?

A different way to frame this question is to note that technological innovation and institutional design are symbiotic, and that when regulatory institutions do not evolve along with technology they can become maladaptive and counterproductive to our broader social goals of economic efficiency and equality of opportunity. The interaction between technological change and retail regulatory and market design is substantial, and can either be positive or negative for consumers, for entrepreneurs, and for incumbents.

The GridWise Olympic Peninsula case study

The GridWise Olympic Peninsula project is a concrete research project that illustrates these ideas. The Olympic Peninsula is located in Washington, in the northwest corner of the USA, and residents in this area use electricity primarily for winter heating. Population growth in the area has created a constrained electricity distribution network, with expectations of further future constraints. The traditional regulated utility response to demand growth is, naturally, to increase capital investment in generation and wires capacity, because under rate-of-return regulation the firm's profits are a function of its 'rate base', its capital stock. Two challenges to this traditional response presented themselves – population and demand are growing because people move to the Olympic Peninsula for its natural beauty, and do not want it despoiled by more generating and distribution capacity, and the physical terrain of the area would make such infrastructure construction extremely costly. Thus, the proposal came from researchers at the Pacific Northwest National Laboratory to look at digital end-use technology and retail pricing as ways to increase capacity utilisation with the existing network assets.[3]

Homeowners participating in this project received a transactive, price-responsive communicating thermostat and water heater, and they could choose from among three different retail contracts:

- *Fixed price:* the price per kilowatt-hour did not change over time, and reflected the insurance premium for the insurance that the consumer received against price volatility;
- *Time of use (TOU):* this peak/off-peak price structure included a higher price in peak hours (6am–9am and 6pm–9pm) and a lower price during all other hours; and
- *Real-time price (RTP):* the energy portion of the consumer's price fluctuated to reflect real-time changes in the wholesale electricity price (as approximated in this project by the Dow Jones Mid-Columbia wholesale price). This price could change as often as every five minutes.

They also had in-home visual displays that made changing settings easy – if you can programme a digital video recorder you can control your own electricity use according to your preferences using this technology. The experiment also included a control group with technology that did not participate in the retail choice treatment.

The most novel institutional design innovation in the project was the design of a double auction for the RTP contract customers. A double-auction market design has active buyers and sellers simultaneously submitting bids and offers, which creates an information-rich environment that converges to equilibrium more quickly than other market designs. In this double-auction retail market, the household's transactive appliances submitted bids, while suppliers submitted offers to supply. This market cleared every five minutes for a year, and is the first use of a retail, real-time double-auction market.

In brief, the results of this year-long project were customer savings, increased distribution capacity utilisation and high reliability. On average, customers saved 10% on their bills, peak demand fell by 15% and overall electricity consumption fell, resulting in multiple types of conservation.

The RTP customers saved the most money, and the TOU customers reduced their consumption the most. This project provides just one example of how retail choice and product differentiation can be welfare-enhancing for individual consumers and also achieve system-related policy objectives. Other test beds and projects in the USA are finding corroborating results, although none has yet implemented a real-time double-auction retail market design (but some are working towards it).

Note also that extrapolating the results of this project nationally would suggest substantial avoided investment over 20 years. This avoided investment would mean lower production costs (other things equal) and long-term environmental benefits due to reduced resources being used to meet electricity demand.

This project is a concrete example of my main points:

- The symbiosis of technology and institutions is crucial for achieving the greatest potential value for electricity consumers from technological change (transactive technology + portfolio of retail products).
- Technology and market design can combine to transform a complex system into a complex *adaptive* system, harnessing edge intelligence to create economic and environmental value by empowering residential retail consumers to control and manage their own electricity consumption decisions and use technology to automate their responses to dynamic prices.
- Technology and market design can lead to emergent order through decentralised co-ordination rather than the hierarchical physical and economic control on which this industry has relied for the past century.

Consumer-focused smart grid innovation

Digital communication capabilities in the network, including in end-use devices, provide increasingly feature-rich, mobile ways to create consumer awareness about electricity consumption, electricity expenditure and the environmental impact of that consumption. They also provide ways to change electricity consumption, either manually or automatically, in the home or remotely. For example, a home can have a home area network (HAN) that connects its appliances, its heating and cooling, its water heater, its laundry, its entertainment (stereo, TV, DVR, game console) and its lighting into one communication network, accessible either through a computer screen in the home or a web-based portal that can be accessed via a computer or a web-enabled mobile device. Through this communication interface, the customer's electricity retailer can communicate real-time information about the quantity of electricity consumed, the price the consumer is paying, and even the type of generation resources being used to generate the power being consumed. The retailer can also communicate price signals to the customer, and the customer can program the different devices in the HAN to change their settings in response to price changes – e.g. if the price increases from nine cents to 12 cents, reduce the temperature in the water heater by five degrees, and increase the thermostat air conditioner setting by five degrees. Moreover, the consumer can have remote web access to the HAN, and can change settings, monitor energy consumption and analyse data on the home's electricity consumption.

Say, for example, you are on the train to work and you get an SMS notification that due to unexpected weather, there will be a higher-than-normal electricity price between 9am and 10am. You may have already programmed your devices to respond to price signals, but what if the price is high enough that you want to change your settings? You can log in to your

HAN from your mobile device, or from your computer at work, and change the device settings in the home through the web portal.

Such functionality requires intelligent end-use devices, which are increasingly feasible and cost-effective as the costs of information technology fall. Intelligent devices include thermostat, water heater, television and so on that have digital communication capability. Intelligent devices can have their settings changed remotely and can be programmed to respond to data, including price signals.

Furthermore, if the home has distributed generation installed, such as solar photovoltaic rooftop panels, the customer can program the network to reduce electricity use once the home's consumption reaches the generation capacity of the solar resource, thereby reducing the use of energy overall and reducing the use of fossil-fuel-generated power if the marginal generation resource at that time is coal or natural gas (of course, with retail choice, the customer could choose a 100% renewable energy contract if desired, which would alleviate the green/grey mix consideration). These digital communication technologies enable new value creation, reduction in environmental impact, and decentralised co-ordination in the electricity industry precisely because they make more of the network, and more of the participants in the network, transactive.

One of the hallmarks of smart grid technology is how it enables and reduces the cost of two-way communication. 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, as communication technology has proliferated it makes it easier and cheaper to engage in transactions. The implications of this for the electric power network are a smart grid that is a rich transactional environment, a market platform, 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.*

Take a non-electricity example – personal banking. Two innovations have transformed personal banking: the ATM and the internet. The digital communication technology that the internet comprises enables us to do our banking online instead of going to a branch or doing bank-by-phone. The transactions in which we engage with our bank are thus easier, quicker and cheaper for us. Furthermore, we can use this technology to automate our actions, such as scheduling recurring bill payments, or establishing trigger rules by which we receive alerts about our account status or activity. Digital communication technology enables us to bank any time, from anywhere. The value creation due to this transactive capability has been enormous, and has largely been in the form of consumer surplus/benefit (with some increases in retail banking profits before the current recession).

Digital communication technology lowers transaction costs. Transaction costs reduce the extent to which private parties engage in mutually beneficial exchange, thus as the internet has grown and our communication capabilities have expanded, our transactiveness has also increased dramatically. Banking is just one example; others include online shopping and eBay.

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. But the most important implication of transactiveness for the electric power industry is the effect on firms. High transaction costs provide one reason for vertical integration, and have contributed to the vertically-integrated firms that have been the producers in this industry for a century – where transaction costs are high, firms make their transactions internal instead of through markets. But the transaction cost reductions arising from digital communication technology shift the margin at which it is profitable to organise transactions within a firm instead of through markets. If it is now cheaper to transact in markets, then transactive activity should shift from within-firm to between-firm, and the boundaries of firms should change. Vertically-integrated firms exist for several reasons (not the least of which in electricity is historical path dependence), and transaction costs provide only one reason, but lower transaction costs will contribute quickly to the increasingly stand-alone capability of both the generation and the retail portions of the electricity supply chain.

From the consumer's perspective, the implications of a transactive smart grid are profound. Take the personal banking experience and the GridWise Olympic Peninsula project example, and imagine what that kind of transactive capability would be like with respect to our energy use. Online home energy management, remote access, the ability to automate our electricity consumption decisions, the array of new products and services that could make use of this transactive functionality. 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 a large range of value potential for consumers, producers and entrepreneurs.

A smart grid is a transactive grid

The reverse is also true. If a communication-rich electric power network does not take advantage of this transactive capability, we forsake all of this value creation. We still get value from the engineering-related optimisation of power flows, of fault detection and repair, and of distribution automation. But the engineering-related possibilities of a smart grid are only the tip of the iceberg: they are tweaks and improvements on the physical management of a closed-loop system. The true, meaningful, resilient and long-lived value proposition in smart grid is in enabling the multitudes of diverse, distributed, heterogeneous agents in the electric power network to exchange with each other for mutual benefit; in enabling a neighbourhood to form a microgrid and exchange among themselves; in enabling me to make a choice of whether to pay my employer for allowing me to charge my plug-in vehicle, or whether to sell my employer some of my stored electricity in the battery of my plug-in vehicle; and in allowing consumers to choose dynamic pricing and empowering them to use the technology and the price signals to control and manage their own electricity use. In other words, if a grid is not transactive, it is not a smart grid.

But what are the likely outcomes if we invest in such smart grid technology, but retain our historic method of regulating retail prices?

Smart technology, dumb pricing

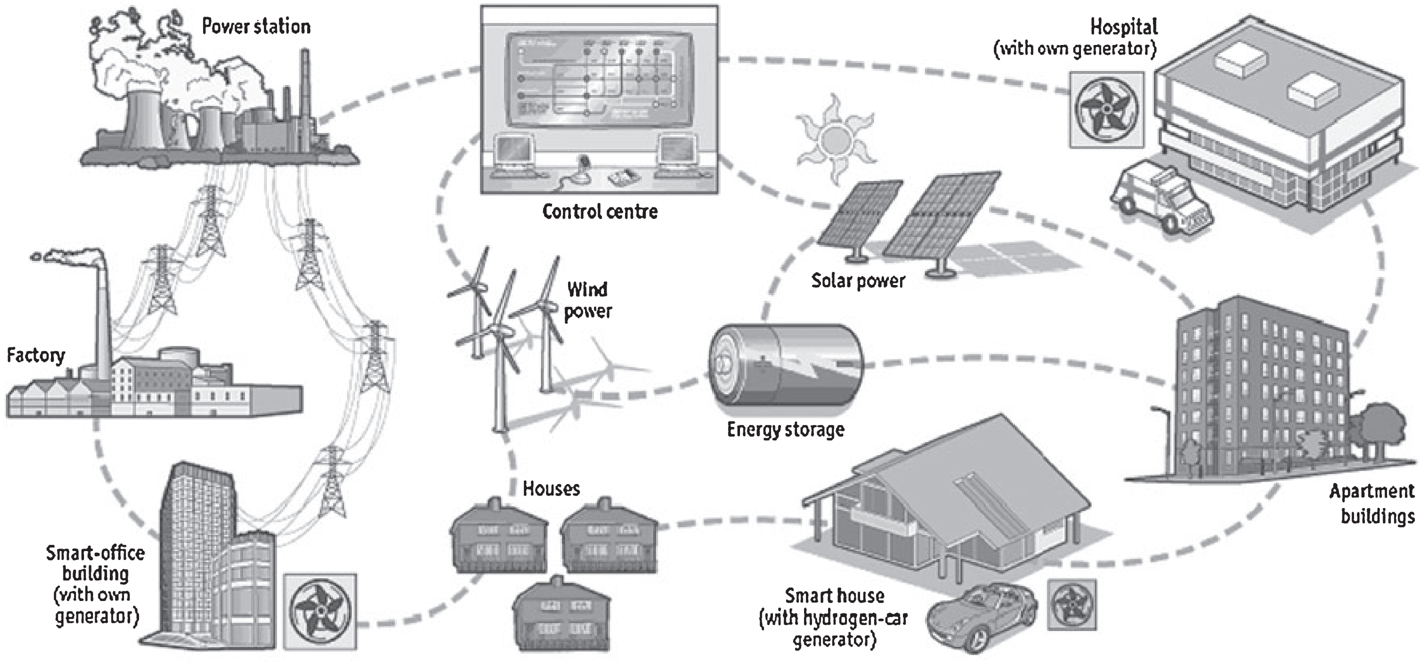
The GridWise Olympic Peninsula project and others suggest that smart technology and dumb pricing will nullify most of the potential consumer and system benefits of smart grid technology. Achieving the potential value creation from transactive end-use technology also requires enabling consumers to choose how much price volatility they are willing to accept, knowing that they have technology to manage their price responsiveness autonomously. At a minimum, transactive technologies require dynamic retail pricing if these innovations are to create value for consumers. Without dynamic pricing, the power system will fail to deliver efficiency and value to consumers. The 'one size fits all' of regulated and fixed retail rates is obsolete because of technological, institutional, regulatory and cultural changes that have created a diversity of products and services that the electricity industry can profitably sell to consumers. Dynamic pricing is necessary to maximise the value of technological innovation and other market reforms that characterise the most valuable, flexible and resilient power system; dynamic pricing also is, in and of itself, a valuable step in producing efficient and fair electricity markets.

Dynamic pricing, product differentiation and complementary technologies are the foundation of achieving decentralised co-ordination in the electric power industry. They bring timely information to consumers and enable them to participate in retail market processes; they also enable retailers to discover and satisfy the heterogeneous preferences of consumers, all of whom have private knowledge that is unavailable to firms and regulators in the absence of such market processes. Institutions that facilitate this discovery through dynamic pricing and technology are crucial for achieving decentralised co-ordination. Thus retail restructuring that allows dynamic pricing and product differentiation, that does not stifle the adoption of digital technology, and that reduces retail entry barriers is necessary if this value-creating decentralised co-ordination is to happen.

More generally, transactive end-use technologies make retail competition more feasible and beneficial. The inverse is also true: competitive retail electricity markets will be a platform for unleashing entrepreneurial creativity to enable consumers to get the most out of these technologies, and future ones that we cannot yet even imagine. The vibrant innovation in consumer electronics in the past 15 years illustrates this technology-institutions symbiosis that leads to consumer benefits and economic growth.

The present and future of the electricity system

These technological and institutional innovations would have implications beyond the individual consumer. Consider the electric power network as a system of interconnected individuals and physical assets. Historically, the technology, economics and business model in the industry has been a linear value chain with substantial homogeneity among the agents in the network, and with the delivery of value being uni-directional – the sale of generated electricity to end-use consumers. As Figure 1 suggests, technological



Sources: *The Economist*; ABB

Figure 1: The future smart grid value network

innovation is going to transform this traditional, linear value proposition.

Technological innovations in both supply and demand will transform the system into a value network, not a chain. The variety of resources and types of 'loads' increase, and now many agents have the technology that enables them to be a producer and consumer or a buyer and seller. These changes increase the complexity of the system. In such a complex system, adaptation to unknown and changing conditions is crucial for reliability and is also a way that consumers can benefit beyond the traditional benefits of generic electricity consumption. For example, home-level distributed generation and storage may improve the reliability of service for that homeowner, even if their normal consumption exceeds the capacity of their on-site generation. It also makes the network as a whole more resilient, because if an unanticipated shortage arises (such as an unplanned generator outage), a price signal would ripple through to the consumer indicating a higher price. This may induce a shift more use of the person's own generation or a reduction in demand by automatic changes in appliance settings. The individual could also sell electricity they generate to other consumers in the market. Similarly, if a homeowner has an electric vehicle, it is also an electricity storage device, which gives the owner the potential to be both a buyer and a seller of electricity. The home management system could be programmed and the vehicle used to sell stored electricity into the market, based on trigger prices that are set to reflect the owner's preferences.

The most effective and efficient system for enabling these adaptations is to use the technology's transactive capabilities to respond to price signals – in other words, enable these heterogeneous agents with their own private knowledge about their preferences and costs to co-ordinate using market processes.

Some policy implications

One of the largest challenges facing the electric industry and policy-makers today is the mismatch between regulatory and technological inertia within the industry and the vibrant, thriving economic and social dynamism that technological change has helped to create in nearly all other aspects of human society. Is it possible for regulatory institutions to be less subject to inertia and to be more adaptive to unknown and changing conditions such as innovation, changes in fuel costs and changes in environmental policy? Are regulators willing to enable the paradigm shift from control to co-ordination? Doing so would require regulators to shift their emphasis from retail rate structures and evaluations of cost recovery and towards retail choice, retail competition, market design and reducing transaction costs. It will also require reframing the idea of 'the public interest' away from its current narrow focus on low, stable retail prices to include environmental benefits and other more general concepts of consumer choice, product availability and consumer empowerment. Such an evolution of regulatory policy will mean incorporating more theories and practices from competition policy and an increased focus on information provision and consumer protection instead of retail rate determination.

One of the most effective institutional changes to enable decentralised co-ordination is to open retail electricity markets to competitive entry. Removing retail entry barriers and enabling retail competition would facilitate the promulgation of dynamic pricing options and product differentiation that could include green power and priority insurance, among other things. The decentralised and distributed network of retailers and customers can also contribute to grid resiliency and flexibility through more active participation in the market. Even if the magnitude of the shift in consumption is small, the effect may be large because of the non-linear relationship between peak load reductions and network reliability. A small load reduction at just the right time can keep the system from hitting capacity, can increase capacity utilisation and, in the long run, can reduce required investment in peak resources that sit idle much of the year. Letting go of some of the centralised economic and physical control would increase the resiliency of the system.

Bundling of retail electricity services with other services also has the potential to create value for consumers by making it easy and convenient for them to save money on their electricity bill in combination with other home services they consume, such as home security or home entertainment. For example, in regulated, vertically-integrated states in the USA a company such as ADT home security cannot enter the retail market and offer a bundled energy–home security service; in restructured US states (except for Texas) they have no profit driver to induce them to enter because of default service entry barriers. Reducing the regulatory barriers to enable us to learn if customers value such bundles would be a good thing, particularly for consumers and entrepreneurs.

By establishing preconditions for markets to function and creating an institutional environment in which they thrive, regulation will adapt to change because markets are complex adaptive systems that achieve ordered outcomes through decentralised co-ordination. By allowing markets to function, regulation will also benefit consumers by delivering differentiated products and services at different price points: note also that competition-facilitating regulation also enables entrepreneurial producers to profit from meeting the needs of consumers (who have diverse preferences and diffuse private knowledge). Market processes are positive-sum interactions in ways that traditional regulation cannot anticipate or duplicate.

Technology, automation, regulation and consumer empowerment

Economic growth and technological change have brought the electric industry and its regulation to a crossroads. Technological change from outside the industry has prompted changes in both regulatory institutions and business models, leading to the incremental disaggregation of the vertically-integrated firm in some regions of the USA and not in others. Simultaneously, increasing use of market transactions within this vertical value chain provides further strains on the existing institutional environment, both in the USA and in other countries as we see both incremental market liberalisation in the USA and the EU and privatisation of the industry in many other countries.

The transactive technology now exists to empower consumers to control and manage their own energy use as they see fit and to automate their choices. These technologies reduce the transaction costs of responding to dynamic price signals. The broader consequence is that transactive technologies enable us to overcome the knowledge problem, by making that 'edge intelligence' in consumer preferences active. This use of market processes to co-ordinate the choices of diffuse private agents is the hallmark of economic dynamism and of efficiency in a complex adaptive system. However, technology alone cannot accomplish this as long as regulatory barriers exist that prevent consumers from choosing products and services that have dynamic pricing. Technology and institutions are symbiotic.

And on the social value of autonomous, transactive technology, I will give the last word to Alfred North Whitehead: 'Civilization advances by extending the number of important operations which we can perform without thinking of them.'

1. This article is an extended version of a Beesley lecture delivered on 1 October 2009, and draws extensively on L. Lynne Kiesling (2008).
2. Kiesling, ibid., Chapter 2.
3. This project was funded through the US Department of Energy's GridWise programme, and project partners included IBM, Whirlpool and the local distribution utilities. For further information see Hammerstrom *et al.* (2007) and Chassin and Kiesling (2008).

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SNP Best-set Typesetter Ltd.	
Journal Code: ECAF	Proofreader: Elsie
Article No: 2000	Delivery date: 30 March 2010
Page Extent: 7	