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The Knowledge Problem, Learning, and Regulation: How Regulation Affects Technological Change in the Electric Power Industry

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Abstract: The economic regulation of the electricity industry, grounded in neoclassical natural monopoly theory, adapts slowly to exogenous technological change, and creates incentives that stifle endogenous innovation. This maladaptive character of regulatory institutions harms consumers, despite the good intentions of their designers. By erecting entry barriers, by focusing the regulated firm's incentives on cost recovery subject to regulatory prudence review, and by specifying the definition and quality of products and services, our existing regulatory institutions stifle the experimentation and social learning that are the outcomes of market processes. This paper focuses on the current smart grid technology investment debates to argue that transactive digital technologies and institutional and market design enable consumers and producers to engage in experimentation and social learning in this industry in ways that were heretofore not feasible, and that such experimentation is welfare enhancing. The case study of the GridWise Olympic Peninsula project illustrates the types of potential benefits that can arise from regulatory change that enables such experimentation.

Keywords: competition, market design, institutional design, regulation, electricity, public utility, experimentation, field experiment, social learning, market process

Civilization advances by extending the number of important operations which we can perform without thinking of them.
(Alfred North Whitehead)

I. Introduction

This paper presents a case study in the potential for technology and institutions to combine to enable decentralized coordination and emergent order. This case involves the last large, regulated infrastructure industry – the electric power industry. The electric power industry has had economic and physical regulation for over a century, during almost all of its existence. This regulation is grounded in static, neoclassical natural monopoly theory. According to natural monopoly theory, if an industry's cost structure displays economies of scale over the relevant range of demand, rivalrous competition will lead to consolidation until a single firm serves the market. This firm can then charge a monopoly price with its attendant deadweight loss. The regulatory institutions arising from natural monopoly theory include the erection of an entry barrier to protect the monopoly, coupled with an obligation to serve all customers in the territory and with profits being limited to a normal rate of return determined by the regulator's evaluation of the costs the monopoly incurs to provide electric service. The regulated firm's products, investments, and profits are determined through a political bargaining process and are grounded in the firm's primary incentive to recover its costs and earn a normal rate of return on them.

While such regulation has contributed to the achievement of widespread electrification and high reliability of service in the 20th century, it did so through investment in generation, transmission, and distribution infrastructure based on a specific technology set – large-scale central generation; an alternating current transmission and distribution grid; electro-mechanical controls, switches, and consumption meters; and static capacitors to act as buffers in a network that requires real-time balance between supply and demand. In fact, the regulatory institutions in electricity, dating from the Progressive era of the early 20th century, are premised on the electricity generation and distribution technologies prevalent a century ago, and their associated cost structures.

Over the ensuing century, though, technology outside of this industry has changed dramatically, yet few of these exogenous digital innovations that could create more value or reduce costs have been adopted in the regulated electricity industry. At the same time, regulatory institutions have not changed significantly from the forms set in place in the early 20th century. Technological change is both inevitable and ubiquitous, yet economic regulation typically does not anticipate it, plan for it, or adapt to it when it does happen. Consequently, over time regulatory institutions become maladaptive, as the environment in which they are designed to operate changes. Yet forces such as inertia, culture, and concentrated interests in maintaining the status quo perpetuate these institutions in their obsolete form.

The historical regulatory institutions in the electricity industry have stifled endogenous innovation in certain directions and promoted it in others. In areas in which (regulated) firms are allowed cost recovery – innovations related to physical "iron in the ground" and supply-focused reliability-related investments – regulators have been more willing to allow new technologies, and have felt that they would be better able to do prudence reviews of those investments than in other areas. For that reason, digital innovations in control room operations have been implemented, but more customer-facing product and service innovations have not.

The burgeoning "smart grid" technologies illustrate this point. Imagine an electric power network capable of connecting the agents in the system using digital communication technology. These agents can enter into contracts and transact in ways they could not before, enabled by communication technology. If these agents have distributed generation, such as solar panels on a house roof or a plug-in electric vehicle, they can transact and interconnect within the network more readily because of digital technology, constrained (of course) by the physics of interconnection on a real-time alternating current network. The technology also makes it possible for such an agent to be either a buyer or a seller, depending on price signals and market conditions. The firms that own the distribution wires can use digital remote sensing and fault location devices to identify and correct line problems before they result in an outage (this capability is at the core of the "self-healing grid" concept). The visibility and transparency that digital technology provides also increases the ways that we can ensure reliability. Current reliability strategy requires a 15 percent or larger generation reserve margin, which necessitates having generators running and burning fuel in case they are needed. Thus this reserve margin creates both economic and environmental costs, which digital technologies can reduce.

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 U.S. was designed for centralized 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 principle illuminating regulation has been a concept of "the public interest" used to control the exercise of market power.

These regulatory and legal concepts are generally static, and do not adapt well to unforeseen and changing conditions, including economic dynamism and technological change. Smart grid technologies enable distributed, individual agents to coordinate their plans and actions transactively, achieving emergent order through decentralized coordination. But regulatory institutions that are designed for centralized control, status quo bias among all agents, and the economic interests of incumbents who profit from that state of affairs, present barriers to achieving this decentralized coordination.

This paper provides a "Bastiat exercise" – shining a light on the unseen – to highlight one reason why this maladaptive character of regulatory institutions is harmful to consumers, despite the good intentions of their designers (Bastiat 1995[1848]). By erecting entry barriers, by focusing the economic incentives of firms on cost recovery subject to regulatory prudence review, and by specifying the definition and quality of products and services, our existing regulatory institutions stifle the experimentation and social learning that are the natural, beneficial outcomes of market processes.

Section II describes the digital smart grid technologies that are being developed, and Section III describes a case study that explores the effects of combining technological change with institutional change to allow customers to have retail choice and price-responsive, transactive devices in the home. Section IV analyzes this case's implications for regulatory institutional choice, focusing on the role of experimentation and social learning as a crucial part of the market process that is lost through regulation.

II. Transactive Smart Grid Technologies[2]

In electricity, technology evolution has taken the form of smart grid technologies in all parts of the electricity value chain – generation, transmission, distribution, and retail service. Technologically, a smart grid is a digital communication overlay and integration into the electric power network. This communication technology includes

- Digital switching networks for autonomous physical flow management;
- Remote sensing and monitoring in wires and in transformers;
- Fault detection and devices for automated fault repair; and
- Intelligent end-use devices in homes, stores, office buildings, garages, and factories.

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

- Transactive coordination of the system (many of the following functionalities contribute to this coordination);

- Distributed resource interconnection, including renewable generation;
- The ability of a resource/agent to be either a producer or consumer of electricity, or both
- Demand response to dynamic pricing;
- 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 systems that the network comprises. The potential ways that smart grid capabilities can create value are large, and they transcend the traditional utility-provided "plain vanilla" electricity generation and delivery value proposition. By enabling better, and more decentralized, coordination of electricity supply and demand, smart grid functionalities contribute to the optimization of resource use in the entire electricity system. One example of this optimization is how dynamic 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 substantial portions of the year. Avoiding that investment by increasing capacity utilization saves costs and saves resources.

A hallmark 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 over the past two decades, the proliferation of communication technology has made engaging in transactions easier and cheaper. The implications of this potential for the electric power network are profound; rather than simply a physical transportation network for the flow of current, a smart grid 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.

A non-electricity example – personal banking – makes the point more concrete. Two innovations have transformed personal banking: the ATM and the Internet. The digital communication technology that the Internet comprises enables online banking instead of going to a branch or doing bank-by-phone. The transactions in which consumers engage with a bank are thus easier, quicker, and cheaper for both consumers and producers. Furthermore, consumers can use this technology to automate actions, such as scheduling recurring bill payments, or establishing trigger rules by which we receive alerts about account status or activity. Digital communication technology enables banking at 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 (with some increases in retail banking profits before the current recession).

The benefits of the global ATM network and online banking did not arise solely from the technology, though. They required the development of crucial institutions to enable interoperability, shared understanding of data across agents, legal contracts, and privacy protection across millions of individuals, firms, and countries. The revolution in personal banking is one of the most visible, and beneficial, examples of how an institutional context that enables experimentation can transform an industry, generating substantial consumer surplus.

This example also indicates how digital communication technology, and an institutional framework that complements its implementation, 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; online shopping, eBay, and all of the other economic transactions in which consumers engage using the Internet reinforce this claim.

From the electricity consumer's perspective, the implications of a transactive smart grid are profound. Take the personal banking experience, and imagine what that kind of transactive capability would be like with respect to residential energy use. Online home energy management, remote access, and the ability to automate electricity consumption decisions are some examples of 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 lots of value potential for residential consumers and for the producers and entrepreneurs who provide them the products and services they value.

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, television, digital video recorder, 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 – if the price increases from 9 cents to 12 cents, reduce the temperature in the water heater by 5 degrees, and increase the thermostat air conditioner setting by 5 degrees. Moreover, the consumer can have remote web access to the HAN, and can change settings, monitor energy consumption, and analyze data on the home's electricity consumption.

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 s/he desires, which would alleviate the green/grey mix consideration). Some of the value of smart grid technology is grounded explicitly in product differentiation to increase welfare by satisfying heterogeneous, subjective consumer preferences, such as preferences over the fuel used to generate electricity. These digital communication technologies enable new value creation, reduction in environmental impact, and decentralized coordination in the electricity industry precisely because they make more of the network, and more of the participants in the network, transactive.

III. Case Study: GridWise Olympic Peninsula Testbed Project

Do these hypothesized consumer benefits from transactive physical control and economic coordination arise in real contexts? A recent research project tested this question, and illustrates the general arguments presented above about smart grid technologies. Intelligent end-use technologies enable autonomous response to price signals and reduce transaction costs in retail markets, as well as providing timely and transparent consumption information to consumers. In combination with retail contract choice, these technologies create value for consumers individually and by contributing to maintaining system reliability.

A. General Description

The GridWise Olympic Peninsula Testbed project was a demonstration project, led by the Pacific Northwest National Laboratory (PNNL), testing a mixed residential, commercial, and industrial power distribution utility network with highly distributed intelligence and market-based dynamic pricing.[3] Washington's Olympic Peninsula is an area of great scenic beauty, with population centers concentrated on the northern edge. The peninsula's radial electricity distribution network is connected to the rest of the network through a single distribution substation. While the peninsula is experiencing economic growth and associated growth in electricity demand, the natural beauty of the area and other environmental concerns mean that the residents wanted to explore options other than building generation capacity on the peninsula or building additional transmission capacity.

This project tested the combination of enabling end-use digital technologies and market-based dynamic pricing to investigate the effects of dynamic pricing and enabling technology on utilization of existing capacity, deferral of capital investment, and the ability of distributed demand-side and supply-side resources to create system reliability. Two questions were of primary interest in this project: (1) what dynamic pricing contracts are attractive to consumers, and how does enabling technology affect that choice? (2) to what extent will consumers choose to automate energy use decisions?

116 broadband-enabled households with electric heat-pump heating participated in the project, which lasted for the year April 2006-March 2007. Of these, 112 remained in the project for the duration of the study. Each household received a two-way programmable communicating thermostat (PCT) with a visual user interface that allowed the consumer to program the thermostat for the home, and specifically to program it to respond to price signals if desired. Households also received water heaters equipped with a GridFriendly™ appliance (GFA) controller chip developed at PNNL that enables the appliance to receive price signals and be programmed to respond automatically to those price signals. Consumers could control the sensitivity of the appliance through the PCT settings.

These households also participated in a retail market field experiment involving dynamic pricing. While they continued to purchase energy from their local utility at a fixed price, they also received a cash account with a pre-determined balance that was replenished quarterly based on their historical energy consumption. The energy use decisions they made would determine how much was deducted from their cash account, and they were able to keep any difference as profit. The worst a household could do was a zero balance, so they were no worse off than if they had not participated in the experiment.

After signing up for the project, homeowners received information and education about the technologies available to them and the kinds of energy use strategies and automation of decision-making made possible by these technologies. They were then asked to choose a retail pricing contract from three options: a fixed-price contract (with an embedded price risk premium), a time-of-use (TOU) contract with a variable critical-peak pricing (CPP) component that could be called in periods of tight capacity, or a real-time price (RTP) contract that would reflect a retail-level market-clearing price in 5-minute intervals.[4]

The RTP was determined using a uniform price double auction, in which buyers (residential, commercial, and industrial) submit bids and sellers (wholesale and retail-level distributed generation) submit offers simultaneously. The digital technology in the household enabled residential customers to participate actively in such frequent markets because they could automate the bidding of their demand functions into the market. One of the original contributions of this project is that it is the first instance in which a double auction retail market design for residential customers has been tested in electric power.

The households ranked their contracts, and were then divided fairly evenly among the three types and a control group that received the enabling technologies and would have their energy use monitored, but did not participate in the dynamic pricing market experiment. All but 11% of the households not placed in the control group received either their first or second choice (49% and 16% respectively); interestingly, nearly 90% of the households ranked RTP as their first or second choice. This result counters the received wisdom that residential customers want only reliable service at low, stable prices, but may be enhanced by an early-adopter effect. 30 households were in the fixed price contract, 30 were in the RTP contract, 31 were in the TOU contract, and 25 were in the control group that received the digital technology but did not participate in the market experiment.

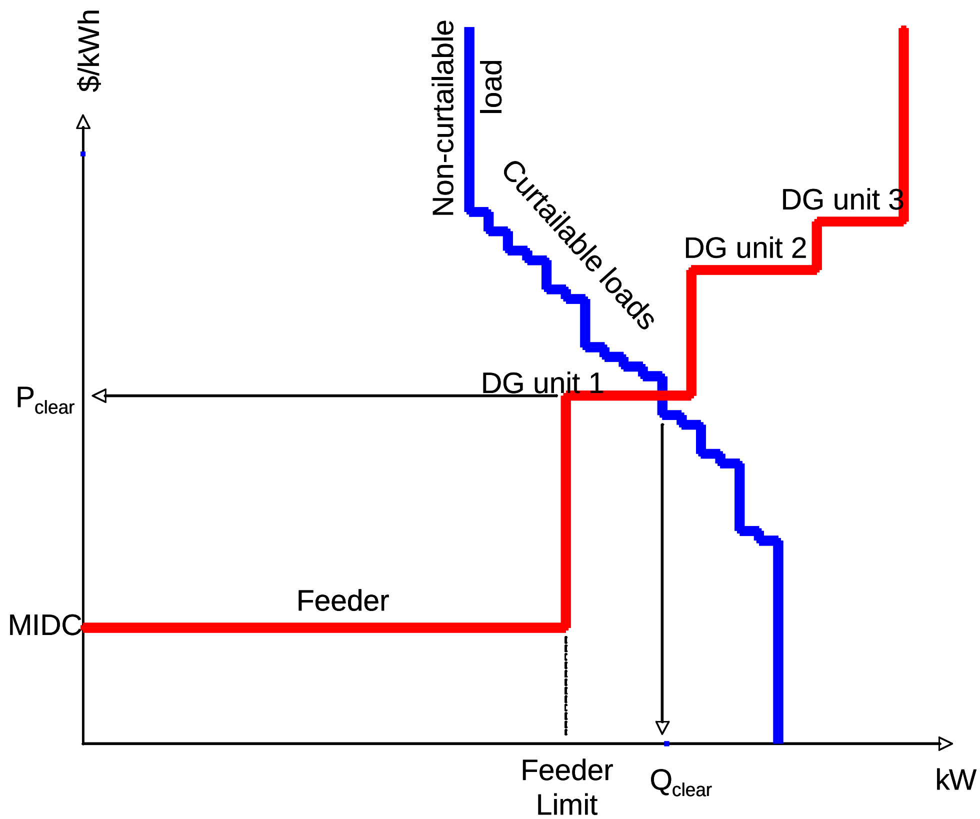
The control group participants were not charged for their energy consumption. Fixed price group participants were charged 8.1¢/kilowatt hour (kWh). The TOU participants were charged peak and off-peak prices under two different rate structures depending on the season. The RTP participants were charged the price of energy as cleared every five (5) minutes in a retail uniform-price double auction market.

The system was operated with different constraints on the distribution feeder at different times of year. From Apr 1 to Sep 22, the feeder capacity was set to 1500 kilowatts (kW) and the mid-Columbia River (MIDC) wholesale price of power reported by Dow Jones was bid at the feeder level. From Sep 22 to Dec 8, the feeder capacity was reduced to 500 kW, and from 8 Dec to Mar 31, it was increased to 750 kW. Altering the feeder capacity enabled us to test how capacity constraints would affect retail prices, and how customers would respond to those prices; it also created the opportunity to observe the extent to which their decentralized decisions would aggregate into system reliability and other desirable system characteristics.

B. Real-Time Price Market Design

The behavior of the residential customers on the RTP contract, and the features of the real-time retail markets in which they participated, illustrate the ability of transactive digital technology and a double auction market design to lead to decentralized coordination of the electric power system. Figure 1 represents how the active RTP households and the DG resources could interact to determine the market-clearing price in 5-minute intervals.

Figure 1: Representative Supply and Demand in 5-Minute RTP Market



These institutional design and technology features provided the environment in which individual participants made their own electricity consumption and behavior automation decisions.

In this field experiment, buyers have a cash endowment and their own individual preferences, and sellers have their individual cost schedules. Buyer *j* has a positive, finite value d_j for the first unit, and diminishing marginal utility $\partial d_j/\partial q_j<0$ (for all j). Seller *i* has a positive, finite cost $c_i>0$ (for all i).

Trade occurs during a finite, pre-determined time interval, [0,T]. During that interval, buyer *j* can submit a bid $b_j(t)$, and seller *i* can submit an offer, or ask, $a_i(t)$ (t [0,T] for all i,j). At the end of the interval the automated market algorithm ranks all bids in declining order, ranks all offers in increasing order, and uses those market demand and supply curves to determine a market-clearing price and quantity, $(p^*(t),q^*(t))$, such that $b(t)=a(t)$. The double auction is a uniform price auction, so all buyers with $b_j(t) \geq b(t)$ and all sellers with $a_i(t) \leq a(t)$ have transacted at $p^*(t)$. This process is then repeated.

C. Results and Analysis: Consumer Benefits

The overall results of the project for all participants, not just the RTP contract group, provide evidence for the welfare creation from the combination of transactive digital technology and institutional design. Table 1 presents the average hourly household energy consumption by contract group. The average household in the TOU contract group consumed the least electricity per hour (1.42 kW), followed by the average fixed price customer (1.79 kW), the average RTP customer (2.1 kW), and finally the control group (2.116 kW).

Table 1
Mean and standard deviation of hourly household energy use by group

Group	Mean (kilowatts)	Standard deviation	Number of observations
Control	2.116	1.25	8759
Fixed price	1.790	0.84	8759
TOU	1.420	0.77	8759
RTP	2.100	1.00	8759

These consumption patterns across groups differ statistically from each other based on nonparametric pairwise Wilcoxon signed-rank test across the groups (Hammerstrom et. al. 2007: 7.6). Thus the type of dynamic pricing contract did shape individual behavior. Furthermore, note that the incentives inherent in different forms of pricing led to different average consumption beyond just having the technology, as was the case for the control group. This result suggests that simply the transparency and information provided by the technology does not necessarily reduce electricity consumption as effectively as the combination of the technology and the dynamic pricing with its embedded economic incentives.

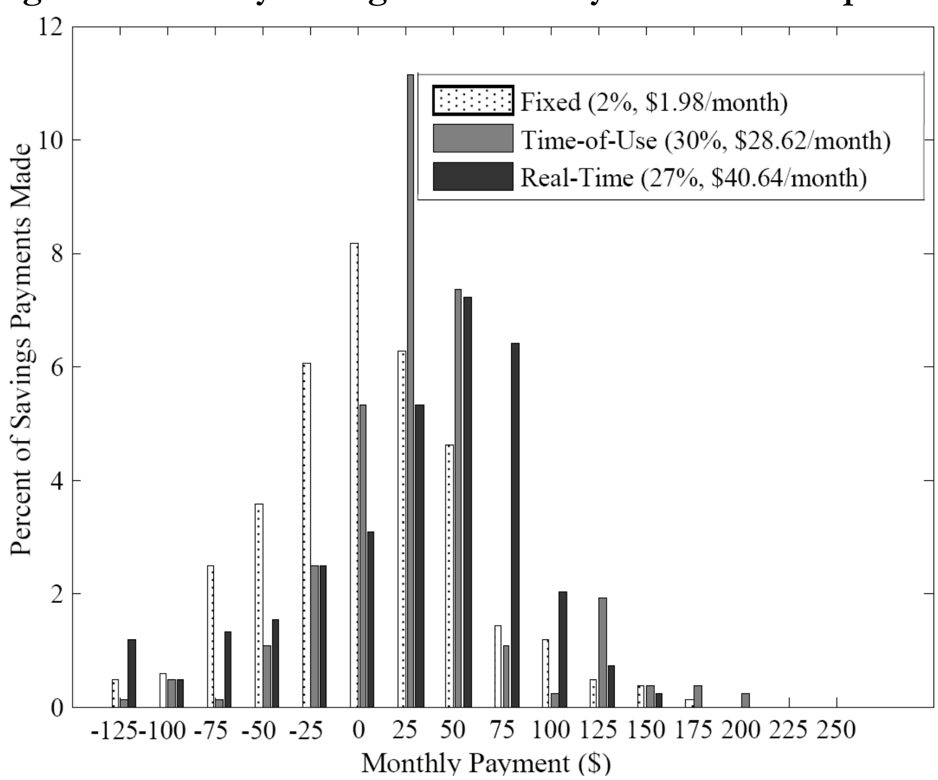
Table 2 reports the average hourly price per megawatt hour (MWh) by contract group. This price was computed by dividing the total energy consumed by the total payments made for each contract group. In the case of the control group, this price could not be computed because they did not pay for energy used within the construct of the experiment.

Table 2
Mean and standard deviation of hourly average price/MWh by group (dollars)

Group	Mean ($/MWh)	Standard deviation	Number of observations
Control	n/a	n/a	n/a
Fixed price	81.000	0.000	8759
TOU	63.271	35.904	8759
RTP	49.198	47.462	8759

The low average price for households on the RTP contract indicates that the RTP customers used their digital automation and control capabilities to shift their consumption to less expensive times. The customer savings achieved corroborate this observation. Figure 2 shows average household savings by contract group.

Figure 2: Monthly Savings Estimate By Contract Group



Participants in the fixed-price contract received about 2 percent savings relative to the control group; the TOU group saved 30 percent and the RTP group saved 27 percent. The distribution of the savings differed across the three groups, with the RTP savings skewed substantially to the right of the other two groups. This distribution of RTP savings indicates the significantly greater savings earned by the RTP customers who selected the most economical appliance settings, relative to those who selected more comfort and did not earn such savings. While not an explicit elasticity estimate, this result suggests that RTP customers were price sensitive and succeeded in using digital automation to respond transactively to changing prices.

Finally, the project's participants were very satisfied with the technology and the pricing with which they experimented during the project. Final project participant surveys indicate that 80 percent of participants were either very satisfied (51%) or somewhat satisfied (29%) with the end-use technology, and that 82 percent were either extremely likely (48%) or very likely (34%) to participate in a program like this one if it were offered again (Hammerstrom et. al. 2007: A.11).

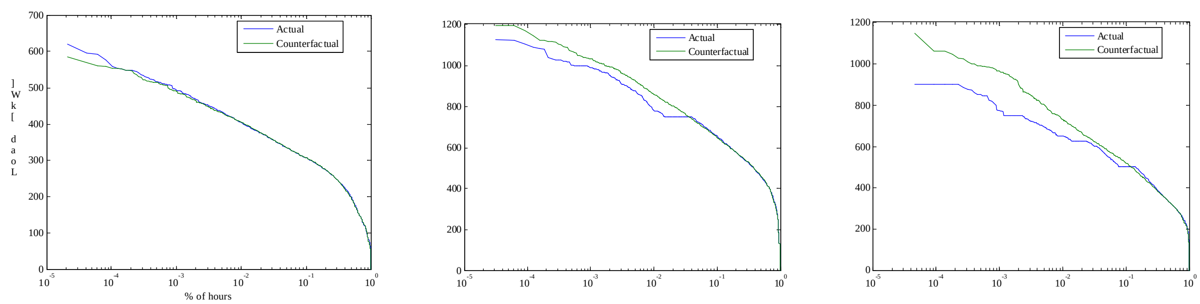
D. Results and Analysis: System Benefits Arising From the RTP Group

For meeting reliability and long-term infrastructure capacity objectives, an important measure of the effect of transactive digital technology and institutional design is the reduction in peak demand among RTP customers. In terms of peak demand reduction, the RTP group saw peak consumption decreases of 15-17 percent relative to what the peak would have been in the absence of the dynamic pricing. Figure 3 shows the actual and the counterfactual load duration curves (graphed logarithmically) divided among the three system condition categories during the year: when the distribution feeder was unconstrained, moderately constrained, and severely constrained. The horizontal axis shows the total number of hours, in percentage terms, that consumption occurred at a particular level; the vertical axis shows the level of consumption, expressed logarithmically.

A load duration curve shows the distribution of consumption over time; if consumption were distributed uniformly, the load duration curve would be a straight line, and capacity utilization or load factor would be the same at all times. Flattening the load duration curve, which indicates shifting some peak demand to non-peak hours, improves capacity utilization and reduces the need to invest in additional capacity, for a given level of demand. The peak load reduction due to the RTP group is seen at the top left corner, where the actual curve is substantially below the counterfactual curve. In particular, Figure 3(c) presents the load duration when the distribution feeder was most constrained.

This result shows how extensively the RTP market and demand response automation reduced demand relative to the level of demand without the combination of the RTP market and the distributed residential automation technology. A 15-17 percent reduction is substantial, and is similar in magnitude to the reductions seen in other projects, such as the California Statewide Pricing Pilot (CRA 2006).

Figure 3: Actual and counterfactual load duration curves for (a) unconstrained, (b) moderately constrained and (c) very constrained systems



(a) (b) (c)

The RTP induced a shift in this automated consumption in both constrained and unconstrained feeder conditions. When demand was high and the feeder was constrained, the shift of demand from peak to off-peak was large, induced by the differential between peak and off-peak market-clearing prices. On unconstrained feeder days, however, the moderation of price volatility meant that the thermostats were sensitive to smaller diurnal price variations. While the transactive control strategy did not explicitly forecast future prices, the diurnal nature of the price movements themselves effectively induced opportunistic pre-heating or pre-cooling. The use of pre-heating/pre-cooling is generally viewed as an essential mechanism to mitigate the effect of load curtailment rebound phenomena. Effective pre-use strategies can be very difficult to engineer, and it is encouraging to see that market-based strategies are at least as effective as administered ones.

These results suggest that the institutional design and technology led to consumption behavior in the RTP group that is consistent with important system (and therefore policy) objectives – reliability, real-time system balancing, and increased capacity utilization. They are also consistent with the hypothesis that technology and institutions can combine to enable emergent order through decentralized coordination, even in a network infrastructure industry.

IV. Analysis and Implications for Institutional Design

A. The Knowledge Problem, Experimentation, and Social Learning

The GridWise Olympic Peninsula project and others like it, such as the California Statewide Pricing Pilot (CRA 2006), suggest that technology and institutions are symbiotic, and that smart grid technology alone will not increase surplus as much as the combination of transactive smart grid technology and the freedom to choose dynamic pricing. 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.

The GridWise Olympic Peninsula project also reveals how prone electricity regulation is to the "knowledge problem" critique typically associated with Austrian economics. In particular, regulation stifles the social learning that occurs through experimentation that happens in market processes. This project generated consumer savings, lower prices, peak demand reduction, and high reliability simultaneously precisely because of the decentralized experimentation and the consequent distributed learning that occurred through participation in market choices and processes.

The learning aspect of market processes is crucial for enabling economic and social coordination, because knowledge is diffuse among the individual agents in society (Mises 1920; Hayek 1945, 1978). As Pennington notes:

> … the Austrian school recognizes that much of the knowledge necessary for social and economic co-ordination is diffused throughout society, is to a large extent subjective and far from being 'given' must be 'produced' through a process of social learning. (2004: 217)

With diffuse private knowledge, neither entrepreneurs nor policymakers can know what goods and services will succeed with consumers, and at what prices. Similarly, consumer preferences are not fixed and known *ex ante*, either to others or to themselves. Consumers only learn their own preferences through the process of evaluating available choices against each other, and the relative value of those tradeoffs changes over time and as the set of available choices changes due to entrepreneurial activity (Hayek 1978). Thus by extension, no policymaker or regulator can access such tacit knowledge captured in the minds of individuals. In this RTP market, only in the process of evaluating the tradeoffs and opportunity costs in their electricity consumption decisions do individual consumers learn their own evaluation of those opportunity costs, and that knowledge is unavailable to bureaucrats or regulators except through transactive market activity.

Competitive market processes address this knowledge problem because market processes facilitate social learning. Seeking profit opportunities, different producers use their own skills and knowledge to develop products and services they think will be compelling to consumers, while consumers gather information on and experiment with different products and services, depending on their own assessment of tradeoffs and based on their perceptions of their preferences and knowledge. Over time, the dynamic feedback loop of this experimentation process is where social learning occurs, as consumers re-evaluate their preferences, change their consumption decisions, and create profits and losses for different producers accordingly.

Regulators cannot create or capture this knowledge, precisely because of its diffuse, private, and subjective nature. Regulations based on cost estimates and cost-based rates of return only reflect a small share of the entire knowledge relevant to electricity production and consumption decisions. Such regulatory institutions do not allow for the social learning feedback loops to generate information to enable entrepreneurs to identify new opportunities (Kirzner 1992); nor do they enable consumers to weigh those new opportunities against those already available.

Traditional neoclassical regulation assumes that consumer surplus increases by reducing deadweight loss, or by reducing production costs. By contrast, the potential application of end-use innovation in electricity show the more dynamic process of increasing consumer surplus by changing the nature of the choice set itself. In more organic markets, this process occurs through the simultaneous, parallel experimentation of both producers and consumers. In regulated markets, such experimentation-driven social learning does not occur. Each of the three main pillars of regulation – the entry barrier, cost-based rate of return, and obligation to serve – undermines such social learning.

The presence of a legal entry barrier into the retail electricity market guarantees that the incumbent firm will face no threat of external competition. This lack of competition means, clearly, that no entrant-driven experimentation can affect the market, because all product or service innovation must be sold through the incumbent. Similarly, without such competitive pressure, the incumbent has little incentive for internal experimentation. Realistically the most significant internal driver of customer-facing innovation is customer service complaints, most of which revolve around reliability in the provision of basic electric service, so the consumers also provide little motivation for internal experimentation.

Cost-based rate-of-return regulation gives firms mixed incentives to experiment and generate social learning through market-based feedback processes. While it does give firms incentives to engage in capital-intensive investments that raise their base capital costs (Averch & Johnson 1962), regulators attempt to counter those incentives by subjecting investment proposals to prudency reviews; anticipating such reviews, firms make conservative investment proposals based on known, existing technologies rather than proposals to invest in newer technologies with which firms and regulators have little experience in the industry.

Finally, the regulated firm's obligation to serve all customers in its physical territory implies the regulatory specification of the product types and product quality (reliability, in this case) that the regulated firm is expected to provide. This administratively-determined retail product choice set means that there is no experimentation among consumers because they have no product choice. Realistically, in some areas some residential customers do have some contract choice, but it typically takes the form of the peak/off-peak TOU contract used in the Olympic Peninsula project, so it is extremely limited.

Regulation has made both regulators and regulated utilities very conservative with respect to the technologies they approve/invest in. It has also imposed a particular outcome on all electricity consumers – a specific, constrained product set sold at a fixed, average price. Digital technology has changed the set of potential outcomes by enabling welfare-enhancing product differentiation, but the inertia and conservatism of regulators, firms, and consumers who are used to regulatory control prevent the experimentation from occurring that would create the social learning about what consumers value and what creative retail products and services entrepreneurs can devise.

B. Implications for Institutional Design

Enabling the vibrant transactive network of intelligent devices as examined in the Olympic Peninsula project requires regulatory reform. Regulatory reform is also required to facilitate the experimentation and social learning necessary to discover what features and functions customers value in this truly novel market.

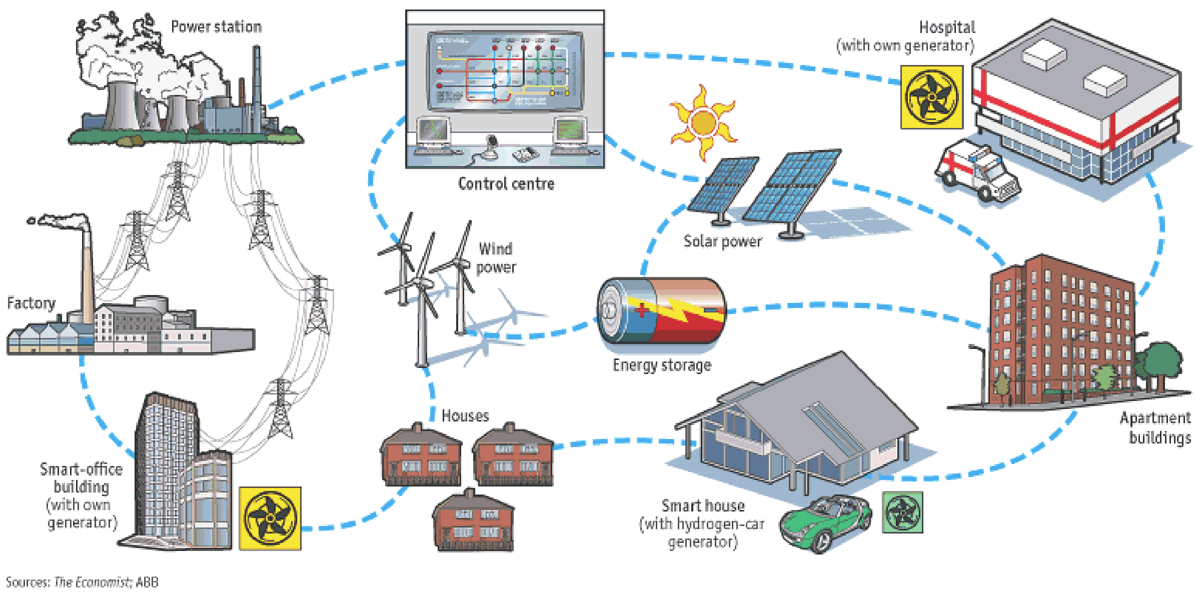
This technological change creates the potential for higher consumer utility, driven by two effects: the potential for product differentiation and the expansion of the consumption choice set, and the potential for rivalry in retail markets that was heretofore not feasible. To create the fullest possible benefits from a smart grid's transactive capabilities, that two-way communicating digital technology inside and outside of the home must be coupled with the freedom to choose dynamic pricing. If regulatory institutions do not allow consumers the freedom to choose how much price risk to bear and what price signals to receive, then they fail to deliver on that potential.

Smart grid's transactive value potential can best be realized through competitive retail electricity markets. What if we had multiple competing retailers, each of whom could offer a menu of product and service offerings to residential customers? Consumers who already have broadband connections can get price signals and the two-way communication capability over the Internet directly to their intelligent end-use devices, and can use a web portal to program their devices and to enable remote access.

More generally, transactive end-use technologies make retail competition more feasible and beneficial. The inverse is also true; competitive retail electricity markets can 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.

This observation about market processes, social learning, and regulation has broader implications for the electric power network as a system. 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. With the types of anticipated innovations in both supply and demand, technological innovations 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 a consumer, a buyer and a 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 "plain vanilla" electricity consumption. For example, if more homes have small-scale distributed generation (such as solar panels) and storage, then consumers can also be producers, and their choices for when to buy and sell can affect others on the network through their effects on voltage and frequency. Similarly, the anticipated future growth of plug-in electric vehicles will make vehicle owners capable of being both supply resources and demand, both buyers and sellers. The traditional electric power network was not designed for the real-time interconnection and interaction of so many small, heterogeneous, distributed agents. The most effective and efficient system for enabling that adaptation 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 coordinate using market processes. Figure 2 illustrates a hypothetical smart electric network of the future to indicate the unprecedented degree of small-scale heterogeneity that is likely to occur in the future, and that would be best facilitated by competitive, rivalrous retail markets.

Figure 2: A Smart Electric Network



Source: The Economist

Bundling of retail electricity service 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; however, existing regulation erects an entry barrier against such bundling. For example, in vertically-integrated, regulated states in the U.S. a company like ADT home security, AT&T, or Comcast cannot enter the retail electricity market and offer a bundled service.[5]

In this market, intelligent end-use technologies create the potential for ubiquitous, timely information in a market that has heretofore been opaque to consumers, who know little about their electricity consumption and only know it *ex post*. Historically, this opacity and the technological difficulty of communicating timely consumption information to consumers has reinforced the dominant economies of scale/subadditivity of costs argument for vertical integration, legal entry barriers, and regulated retail prices. In that context, regulation "stands in for" competitive market forces, and serves to protect consumers from the exercise of market power to raise prices.

However, the exogenous evolution of technology has created a potentially competitive retail electricity market. With more transparent and timely consumption information in the hands of consumers, many more buyers will have the ability to acquire and access timely information about their individual electricity consumption patterns, and the ability to program their demand functions into transactive devices that can respond autonomously to price signals. In other words, the technology now exists to enable consumers to protect themselves from the exercise of market power, one of the traditional functions of regulation.

Yet the retail regulatory institutions in the U.S., except for Texas (Kiesling and Kleit 2009), generally have retained retail market entry barriers. The range is from 14 states with nominal retail competition, where the incumbent utility holds the rights to provide the default service contract (e.g., Ohio, District of Columbia, New Jersey, New York, Maryland, Illinois), to outright refusal to consider modifying the retail regulatory institutions to allow competitive retail entry. Without such institutional change, though, retail consumers are much less likely to have a larger choice set and the ensuing likely increase in total welfare that arises from the experimentation and social learning of both producers and consumers participating in market processes.

V. Conclusion

Regulatory institutional choice is a function of the industry's technology at the time of the institution's implementation. Technology then evolves exogenously, or outside of the industry, ultimately creating a mismatch between the regulatory institutions and the ways that they met the original policy objectives, and the potential for the new technologies to create value and even to meet new policy objectives. The maladaptive nature of regulatory institutions can actually harm consumers relative to what is possible. A primary means by which this harm occurs is by regulation stifling the experimentation and social learning that drives value creation in market processes.

In the case examined in this paper, the prevailing technology at the origins of state-level economic regulation in the electricity industry was entirely electro-mechanical, with large-scale central generation plants exploiting economies of scale to reduce the average cost of producing electricity. Separate monitoring and measurement of current flow was not feasible, so the regulatory institutions developed in the early 20th century were premised on vertically-integrated firms producing and providing a bundled good (generated electric current and its transportation to the end user). The regulatory bargain included an entry barrier for retail competitors and an obligation for the regulated firm to serve all customers in its territory. In return for this entry barrier, the regulated firm would earn a rate of return on its asset base that was the regulator's estimate of the normal rate of return.

Economic regulation is meant to "stand in for" rivalrous competitive markets in situations in which the cost structure associated with the original technology is subadditive. Since those institutions were introduced in the early 20th century, their basic structure and ways of meeting the stated policy objectives have been unchanged, despite the fact that technology has changed dramatically. Over the past 20 years in particular, the evolution of digital communication technology and its application throughout the value chain in many industries, from industrial production to end-use consumer electronics, has transformed how we produce and consume goods and services, and the set of such value propositions available in the market. In the electricity industry, such digital technologies are known as smart grid technologies, which range from digital controls and switches on generators, to digital sensors and switches on transformers and substations, to intelligent end-use devices that consumers can program to transact autonomously.

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 coordinate 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 coordinated outcome, as long as regulatory barriers exist that prevent consumers from choosing produces and services that have dynamic pricing. Technology and institutions are symbiotic.

The reverse is also true. If a communication-rich electric power network does not take advantage of the transactive capabilities of smart grid technologies, we forsake all of this value creation. Value would still arise from the engineering-related optimization of power flows, of fault detection and repair, 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.

It lies, for example, in a neighborhood being able to form a microgrid and exchange among themselves, or in enabling an individual to make a choice of whether to pay her employer for allowing her to charge her plug-in vehicle, or whether to sell her employer some of her stored electricity in the battery of her plug-in vehicle. These value propositions are all grounded 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, which enables producers and consumers to combine to increase welfare through experimentation and social learning.

Notes

[1] I am grateful to the Fund for the Study of Spontaneous Orders for the opportunity to prepare this working paper, to participants in the Fund for the Study of Spontaneous Order conference in December 2009 for their helpful comments, and to Mark Pennington for the discussions that have helped me crystallized my thinking on the topic (although I remain responsible for all remaining errors in fact and logic).

[2] For a more extensive discussion of smart grid technologies and the policy issues surrounding them, see ISGI (2009).

[3] For more information on the project, see Hammerstrom et. al. (2007) and Chassin and Kiesling (2008). This section draws heavily on the project description in Chassin and Kiesling (2008), which provides further details.

[4] While a fully randomized experiment would have allowed us to isolate the different contract treatments and minimize selection bias, we were unable to pursue a randomized experimental design in this project. Consequently, there is selection bias in the participant population.

[5] The competitive environment in "restructured" states is more complicated, but no more appealing to a potential entrant; that analysis is beyond the scope of this paper.

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