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Design Of A Demand Response System: Economics And Information Systems Alignment

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Abstract

The lack of real-time pricing in many retail electricity markets requires implementation of a response mechanism for curtailing demand, particularly during peak load periods. Following a review of transaction cost economics and an analysis of options available, a market based on the exchange of consumption rights is suggested as an alternative to the commonly used hierarchical methods of demand response management. The implementation of smart metering and wireless communication creates the conditions for establishing such a market. Information systems will be required to collect real-time metering data for forecasting demand and monitoring use at the customer and utility grid level, to operate a real-time consumption rights market, to automate individual curtailment plans, and to support market makers to create marketable parcels. The potential outcome is an efficient market-based system for curtailing demand during peaks and thus avoiding the use of expensive reserve generators that are often high emitters of greenhouse gases and other pollutants.

Keywords: demand response; consumption rights; energy efficiency; market

1 The problem of balancing electricity supply and demand

Most electricity markets are supply focused and operate on the principle that hourly demand is "fixed" for a given time or ambient temperature, and that generation must be adjusted to meet fluctuating demand (Sioshansi, 2006). The relative inelasticity of demand means that electricity utilities are continually managing supply to meet current needs, and this is particularly a problem for regions with sharp peaks and few generating reserves. During periods of high demand, there is often a need to deploy inefficient standby generators, many of which have a higher environmental impact per MWh generated, and in future, these might incur high carbon taxes. Attempts to create greater competition in the market have often failed because a few dominant sellers can abuse their market position, especially during periods of transmission congestion (Woo, Lloyd, & Tishler, 2003). As a result, some utilities have implemented demand response systems (DRS) to curtail peaks and thus maintain high levels of efficiency with low pollution. In their current form, DRSs are deemed to be expensive (Sioshansi, 2006) and often inefficient because of their disconnect from the wholesale market (Borenstein, Jaske, & Rosenfeld, 2002). The potential benefits, however, are well worth pursuing with projected savings for Europe of tens of billions of euros, an annual reduction of 30 million tons of CO_2, and pre-empting the need for 150 medium size thermal plants (Capgemini, 2008). There is a need for a new approach to DRS design, which we anchor in information systems infrastructure and design economics.

New infrastructures create opportunities for creative destruction of existing business models (Schumpeter, 1943). The advent of the Internet connected businesses and customers in new ways that decimated some industries (e.g., travel agents) and enabled electronic markets to replace hierarchies in certain circumstances (Malone, Yates, & Benjamin, 1989). Wireless metering is an information-based infrastructure that offers similar potential because it generates real-time digital data streams about consumers' electricity usage. It offers an opportunity to redesign the relationships of the major agents in a demand response system. Fittingly, the 2012 Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel was awarded to two scholars studying how to match agents as well as possible.[1] Thus, we propose addressing DRS problems by combining design economics (Roth, 2003) and Information Systems (IS) to address the demand response problem. This work can also be considered to fall under the umbrella of Energy Informatics, with its focus on " … analyzing, designing, and implementing systems to increase the efficiency of energy demand and supply systems" (Watson, Boudreau, & Chen, 2010). Because a DRS is principally a system supporting transactions between the supplier, the utility, and many consumers, an appropriate first step is to take the broad perspective of transaction cost economics (TCE) to identify potential organizational structures before considering information systems issues.

The objective of this paper is to present the conceptual design for a DRS based on the trading of consumption rights. An examination of the principles of transaction cost economics and current approaches to demand response management lays the foundation for applying the principles of market design to propose a DRS based on a consumption rights exchange.

1.1 Transaction cost economics

TCE is founded on the principle that transactions are the basic units of economic activity, where a transaction "may be said to occur when a good or service is traded across a technologically separable interface" (Williamson, 1993, p. 16). Certainly, this is the case for a DRS where many transactions can be executed when demand needs to be curtailed. Associated with these economic exchanges are transaction costs, which are those outlays over and beyond the price of the product or service procured. They broadly break down into motivation and coordination costs (Milgrom & Roberts, 1992). Motivation costs are composed of opportunism (Williamson, 1985) and agency costs (Jensen & Meckling, 1976), and coordination costs include search (Stigler, 1961), input coordination (Armen & Demsetz, 1972), and measurement costs (Barzel, 1982).

[1] http://www.nobelprize.org/nobel_prizes/economics/laureates/2012/press.html

TCE proposes that organizational designers will choose the governance structure that minimizes the total cost associated with a transaction (Coase, 1937) (see Figure 1). Firms and markets, the two generic structures we observe in economies, are the principle alternative approaches to the governance of economic activity (Arrow, 1974). The selected governance structure should minimize the sum of production expenses and transaction costs (Williamson, 1981). The three key transaction characteristics are (1) asset specificity, (2) uncertainty, and (3) frequency of transactions (Williamson, 1981).

Transaction characteristics → Transaction costs → Governance structure

Figure 1: Transaction cost economics model

Asset specificity is the degree to which the investments necessary for a transaction are specific to that particular transaction (e.g., generating electricity) (Williamson, 1981), and the investor has very limited alternative options for deploying the asset to generate revenue. Asset specificity creates dependencies between buyers and suppliers. Buyers, as in the case of electricity, cannot usually find an alternative supplier, and are thus "locked into" the transaction for a considerable time (Williamson, 1981). Often, governments will regulate an industry, such as electricity generation and distribution, to mitigate asset specificity problems when the economic consequences for the community from lack of investment in generating capacity, a highly specific asset, can be considerable.

Uncertainty arises from variability in the natural and business environments and behavioral uncertainty (Rindfleisch & Heide, 1997).The inability to precisely foresee and anticipate change creates uncertainty (Rindfleisch & Heide, 1997). As a result, it is difficult to develop comprehensive contracts and there is usually a need for the parties to renegotiate and adapt, which increases transaction costs (Williamson, 1979). Behavioral uncertainty, founded on the threat of opportunism, refers to the difficulty of monitoring and assessing the performance of a partner in an economic exchange. Environmental uncertainty limits contract specificity ex ante. In contrast, behavioral uncertainty constrains verification of partner transaction performance ex post (Geyskens, Steenkamp, & Kumar, 2006). High levels of uncertainty tend to result in governance structures based on the command and control structure of a hierarchy. In the electricity business, variability is mainly driven by temperature fluctuations causing higher demand for air conditioning or heating.

According to TCE, the **frequency of a transaction** determines both transaction and production costs. It was initially conjectured that as transaction frequency increased, firms could gain efficiencies by internalizing their execution (Williamson, 1985). However, the Internet changed this viewpoint, and there can be competitive advantages in externalizing many high volume transactions by executing them electronically (Chatterjee, Segars, & Watson, 2006; Watson, Zinkhan, & Pitt, 2004). The rise of outsourcing exemplifies the externalization of many transactions.

Intensity of incentives refers to the directness of the relationship between effort and profits. Incentives with high intensity are assumed to motivate because of the potentially higher reward. Markets characteristically have high incentives. *Control* is the capacity to limit opportunistic actions and to ensure that agents act in the interests of the principal (Demil & Lecocq, 2003). Hierarchies, with their managerial structures and oversight, establish a high level of control.

A DRS can be set up as a market or hierarchy. Thus, the question is whether to rely on incentives or control to create an efficient and effective DRS. Given the information intensity of a large scale, demand response program, information systems are required to support both types of governance structures. We now examine some current DRS designs.

1.2 The electricity system and demand response

The major challenge for the electricity system is to achieve a real-time balance between supply and demand. This problem is exacerbated by the possibility of sudden large changes on the supply side, such as generation and grid outages, and changing peaks in consumer demand during weather extremes. Establishing the capacity to handle outages and peak loads requires large capital investments in specific assets, such as generators and transmission lines. This excess capacity is often

3

required for only a few hours of the year, but can represent a significant financial outlay. Alternatively, utility companies can implement systems for curtailing excessive demand when there is lack of generating capacity or the cost of meeting the demand is very expensive.

Volatility and spikes (Borenstein, 2002) characterize the electricity market in some regions, because there are currently no economic methods for storing electricity in large amounts and generating capacity is not flexible in the short-term (Borenstein et al., 2002). As a result, when demand is high and capacity limited, prices in wholesale markets rise. Sometimes spot market prices become extremely high, as much as USD 7000 per MWh (Deng & Xu, 2009), yet many retail consumers are often insulated from market realities through fixed rate structures. Holding rates relatively constant, however, can lead to power cuts in extreme conditions. Generally, agreements are made in advance for such a drastic action. Such demand reduction programs pay the customer for cutting consumption, and it is typically the system operator that pays the consumer directly or indirectly for the reduction.

2 Approaches to demand response management

A comprehensive review of demand response options identifies five general types of programs: real time pricing (RTP), time-of-use (TOU) with and without demand charges, critical peak pricing, real-time demand-reduction, and interruptible supply (Borenstein et al., 2002). We now deal with each of these and consider their implications for IS.[2]

2.1 Real-time pricing

Real-time pricing (RTP) permits prices to be set for different hours, or parts of the hour, for periods when demand is peaking. An important consideration is the lag between a price's announcement and its implementation. Long lags give consumers more time to make plans to evaluate the consequences of higher prices and reduce demand appropriately. Short lags result in prices that reflect current market conditions but often give consumers little time to adjust behavior. Given that weather is frequently a major determinant of demand and that 72 hour temperature forecasts have an accuracy of about ±2ºC (Silver, 2012), the lag could be reasonably set at 24-48 hours.[3] This should be long enough to allow consumers to react and short enough to ensure prices charged are close to spot wholesale prices.

RTP requires that electricity suppliers create an IS that can accurately forecast demand 24-48 hours in advance and set prices that will be close to wholesale rates during the forecast period. This will require a change in the operational perspective of many utilities, which prefer the right to adjust prices with a minimal time delay. This change could come about if the incentives for utilities were compelling. For effective RTP, there is a need for an IS that electronically notifies consumers and interested third parties of prices as they are set. Consumers will need decision support systems that can advise on action to be taken based on factors relevant to their current business activities, operational flexibility, and electricity prices. Alternatively, the entire process might be automated (e.g., resetting a thermostat).

2.2 Time-of-use

Time-of-use (TOU) is a long-term price setting strategy where prices are typically fixed months in advance for set periods of the day (e.g., peak, off-peak, shoulder). It is essentially RTP with a long time lag. As a result, TOU prices might not reflect current wholesale rates. It will have some impact on peak demand, but it is insensitive to peak demand fluctuations. TOU favors consumers who cannot flexibly adjust demand, but has little impact on those with the ability to act agilely to reduce consumption.

[2] This section draws extensively on Borenstein (2002)
[3] http://www.forecastadvisor.com provides forecast accuracy for any U.S. postcode.

Sometimes demand pricing is used to augment TOU by charging for a customer's peak usage, but this has some shortcomings. A customer's peak might occur at a quite different time from the system's peak. Charging by peak usage doesn't encourage demand reduction until the customer is near the peak for a period. Demand pricing moves TOU somewhat closer to real time pricing but not far enough to be as effective as RTP in reducing demand. Demand pricing also leads consumers to react in a method more akin to avoiding a negative (demand charge) as opposed to realizing a positive. The IS requirements for TOU are quite modest because a dynamic situation, the cost of electricity, is converted to a relatively static and certain factor that can be handled leisurely with precision.

2.3 Critical peak pricing

Critical peak pricing (CPP) sets prices at critical system peaks rather than at a customer's peak, and thus is more consistent with wholesale costs. However, prices are pre-established for critical peaks and the number of critical peaks in a year is limited in order to protect customers from very high prices. Thus, CPP is less connected to market reality than RTP, but more so than TOU, though it does give customers some certainty with regard to price.

2.4 Real-time demand-reduction

Demand-reduction is a real-time program activated by the grid operator to curtail demand. The operator pays a price, usually pre-determined, to reduce consumption. The price does not typically reflect changing and current market conditions and is based on a previously established baseline for the customer determined from prior demand. Demand-reduction is subject to *adverse selection* and *moral hazard*.

Adverse selection occurs when those willing to participate take steps following establishment of a demand response agreement to lower their typical consumption (e.g., conservation programs or production cutbacks) so their pre-determined baseline is artificially high. Thus, the demand reduction is not as great as it appears. Adverse selection could be handled by an IS with access to real-time metering to compute realistic baselines based on current weather and recent usage patterns.

Moral hazard arises when customers don't conserve during normal consumption periods to keep their baseline high so as to get a greater payment for a less painful demand reduction. This of course means that these customers are trading off higher energy costs for potentially higher payments during a demand response event. Moral hazard can be addressed by delinking typical consumption patterns from demand response payments and by establishing two independent sets of incentives (i.e., long-term profit gains from continuous improvement to reduce energy consumption as normal business practice and short-term large energy consumption reductions during demand response events).

2.5 Interruptible supply

An interruptible program gives the operator the right to cease or reduce a customer's usage on short notice to preserve grid integrity. Those declining to accept the order are typically charged an exorbitant rate. Those who comply get some rate reduction or payment. An interruptible program requires a similar transaction oriented IS to demand-reduction so supply can be quickly cut off to certain consumers.

2.6 Summary of demand response market models

The preceding examination of demand response mechanisms reveals a range of approaches from a pure market mechanism of RTP to the hierarchical approach of interruptible supply. What is surprising is that there is a bias among the options towards the control mechanisms of hierarchies and that incentives are often misaligned with the market. For example, TOU and CPP take minimal notice of current market conditions and thus don't allow incentives to work effectively. The central problem is that most DRS methods fail to address the mismatch between the wholesale and retail markets. The electricity supplier is generating electricity or buying real-time at market rates in the wholesale market and is often unable to pass these prices through to the retail market. Because the two markets are out of phase, pricing signals are typically ineffective, except for RTP, as a means of balancing supply and demand.

It might be possible to adjust control mechanisms to create a better DRS, but given the fundamental problem is one of mismatched markets, we believe it is worth designing a DRS that puts greater emphasis on incentives, synchronizes closely with wholesale markets, and operates efficiently.

3 Principles of market design

Design economics focuses on the design of markets and other economic institutions. It can be viewed as a practical interpretation of the issues considered in TCE, and thus gives us another dimension for thinking about the non-IS aspects of DRS design. To work well, markets need thickness to effectively handle congestion and are safe and simple for participants (Roth, 2008). We define and take these three factors into account in designing a market for curtailment in the following discussion.

3.1 Thickness

Thickness can be thought of as describing the depth and breadth of agents in the marketplace. An efficient market requires many well-informed buyers and sellers who can easily enter and exit the market and are willing to trade with each other. Electronic markets, which remove physical location constraints on buyers and sellers, can increase thickness. Accurate real-time prices are an important signal to market participants and can promote thickness. An IS can foster market thickness by increasing its information richness so that it becomes the best place to trade.

3.2 Congestion

Thick markets can be congested because of the volume of transactions processed. In such situations, participants might need time to consider alternatives or be able to quickly review many possible options. An IS can help by providing tools to accelerate alternative consideration or automatic market participation based on pre-established algorithms. These types of information systems reduce congestion.

3.3 Safety and simplicity

Safety refers to the simplicity of market membership and its fairness. As a result, participants are discouraged from seeking other solutions. It means no participant should have sufficient power to dominate the market, and that a smaller participant is not disadvantaged. Transactions should be relatively simple with low transaction costs, easily monitored, and contracts readily enforceable. Safeness is also dependent on creating a marketplace with high transparency and information richness. All players need rapid and transparent access to the key data that determine demand and supply, and thus prices.

Reduction of uncertainty is a means of promoting market safety, and in an electricity market where weather is usually a key factor, it is important to understand the relationship between spot prices and temperature. The U.S. National Weather Service provides 12 and 24 hour forecasts for minimum and maximum temperatures for most major metropolitan areas in the country. We examined the relationship between the average daily price and the maximum temperature during August, typically the hottest month, for US cities (Figure 2). An exponential curve explains 63% of the variation in price with temperature. We also see that there is pattern in the hourly price and the time of day on a very hot day for the same city (Figure 3). The initial evidence suggests that there is a sufficiently detectable pattern in electricity prices to use statistical forecasting techniques to reduce uncertainty.

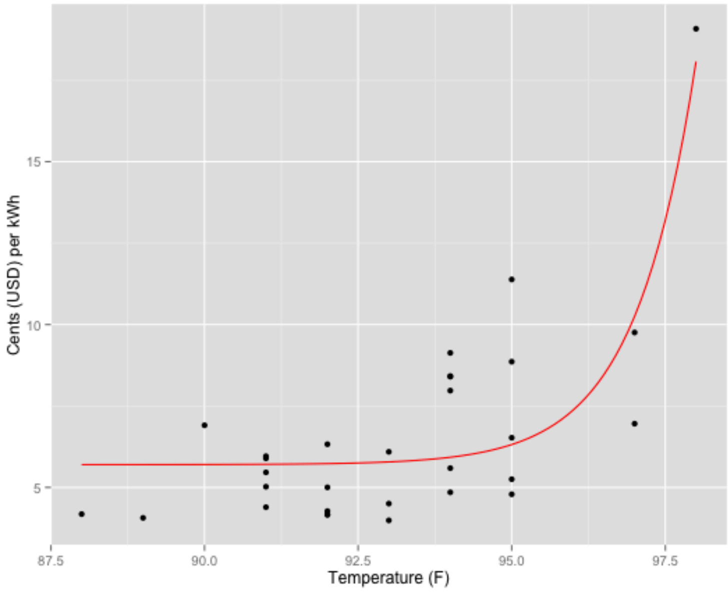

Figure 2: Relationship between price and temperature for a large representative US city

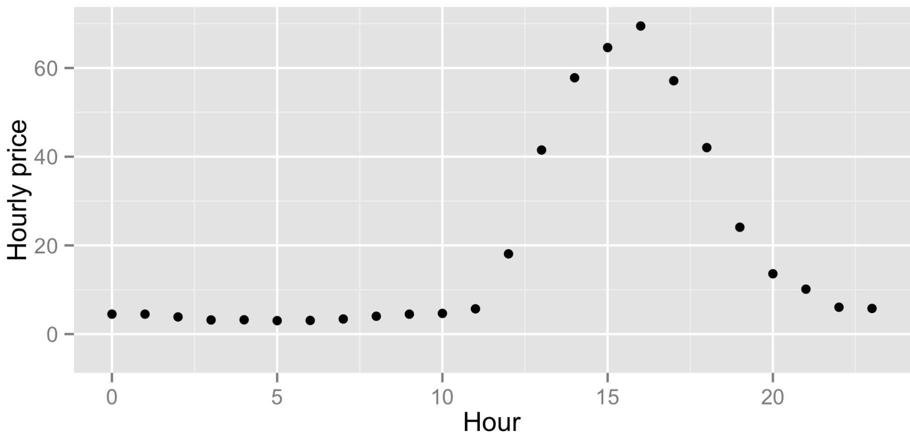

Figure 3: Representative hourly prices on a very hot day

3.4 DRS and markets

TCE and market design principles indicate that a market approach can be applied to a DRS. First, a DRS transaction can be very precise, such as a contract to reduce electricity by a specific number of kWh for a specific time period. Second, the advent of wireless metering makes such contracts easily monitored at minimal cost. Third, electronic markets are not costly to establish. Furthermore, if cloud computing is used, asset specificity is limited to a set of software code. Fourth, potential participants have already made the investment, a computer and Internet connection, to enter the market. Fifth, electricity demand can be estimated with some accuracy in many markets because of the strong relationship to weather conditions, time of day, and day of week. Wireless metering lowers uncertainty because it can provide a high degree of data granularity and thus enables more precise and timelier demand forecasts.

7

4 Consumption rights trading: a demand response system

An electricity customer signs a contract with a supplier that creates a right for the customer to consume electricity and an obligation for the supplier to deliver reliably electricity of a certain specification (e.g., 120 volts ± 10% at 60 Hz). The core problem is that under some situations, the supplier cannot meet its obligations, which will have a varying impact on consumers. As a result, those consumers who can curtail consumption might, with appropriate incentives, be willing to trade all or a portion of their right to consumers with those who must continue to consume.

Consumption rights markets already exist for irrigation water, which shares some characteristics with electricity but differs significantly. In terms of similarity, such water is rarely priced at opportunity or market cost but rather forms of rationing or curtailment are used to limit demand (Thobanl, 1997). On the difference side: it is hard to price irrigation water accurately, the short-term demand does not fluctuate so markedly as electricity, and water can be stored. Formal irrigation water rights trading markets have existed in Australia since the late 1980s (Brooks & Harris, 2008), and the potential to sell water rights creates a fungible resource and encourages conservation (Thobanl, 1997). The creation of an electricity consumption rights trading market could be a viable DRS.

4.1 Modeling an electricity consumption rights market

Assume consumer k curtails δC_k of demand causing a price decrease of δP_k for all consumers (Figure 4). If consumer n requires M_n, then the value created for customer n by curtailer k is

$$V_n = \delta P_k \bullet M_n \qquad (1)$$

The customer with the highest demand gains the most value, which is

$$\max(M_n)\bullet\delta P_k \qquad (2)$$

Thus, this customer should be willing to pay consumer k to agree to curtail at most

$$\max(M_n)\bullet\delta P_k \qquad (3)$$

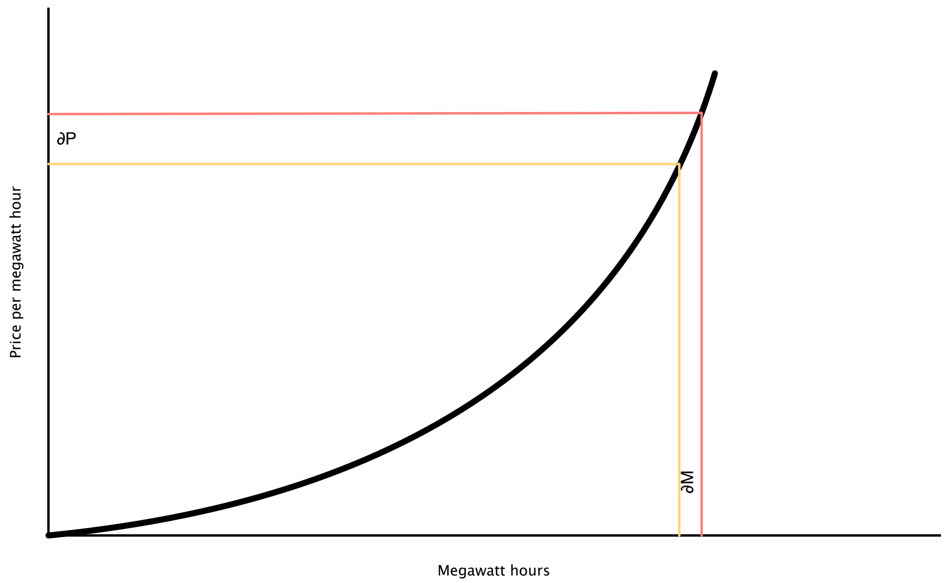

Figure 4: Real-time Price versus Megawatt hours demand

Assuming the curtailer forgoes gain δG_k by curtailing δC_k, the curtailer should be willing to accept a payment for this loss of at least δG_k.

If $\max(M_n)\bullet\delta P_k > \delta G_k$ then we have the necessary conditions for an exchange between the curtailer and the consumer with the highest demand.

$$\max(M_n) \bullet \delta P_k > \delta G_k \quad (4)$$

If this market condition is not met because there is no consumer with $M_n > \delta C_k$ or the inequality is not satisfied, then coalitions of consumers could emerge because when demand is curtailed, every consumer gains. Consumers have a collective interest in persuading consumer k to curtail. Hence, it is likely that a coalition of consumers will cooperate so the point is reached where the total demand they represent is marginally greater than the proposed curtailment and the amount they are willing to pay represents a net gain to the curtailer.

$$\sum_{j=1}^{l} M_j \bullet \partial P_k > G_k where \sum_{j=1}^{l} M_j \geq \partial C_k \quad (5)$$

Similarly, if there is a consumer with a large demand willing to pay

$$M_n \bullet \delta P_k \quad (5)$$

then we can expect a coalition of p curtailers to cooperate so that the point is reached where their proposed curtailment is greater than the demand of M_n and they each gain from the curtailment because

$$M_n \bullet \delta P_k > \sum_{p=1}^{p} \delta G_p where \sum_{p=1}^{p} C_p > M_n \quad (6)$$

In addition, assuming that each member's share of the contract's value is S_p, then for the coalition to exist, we need

$$S_p > \delta G_p \forall p \quad (7)$$

It might also be that market markers emerge to create coalitions of participants to achieve the effects just described. The utility company could also enter the market to buy curtailment contracts.

Wireless metering has created the conditions for an efficient electronic market for managing electricity demand. Thus, allowing consumers to trade their right to consume could create incentives for some consumers to curtail their demand.

5 A market for consumption rights

The electricity supply chain contains wholesaler and retailer markets, with only the wholesale domain having strong market characteristics (i.e., prices dynamically set by supply and demand). In many retail markets, because of regulation, there is only one direct supplier. We propose adding a third element, a consumption rights market, with strong market characteristics (Figure 5). With regard to creating a consumption rights market, we now discuss the market players and their roles. In particular, we focus on what information systems are required.

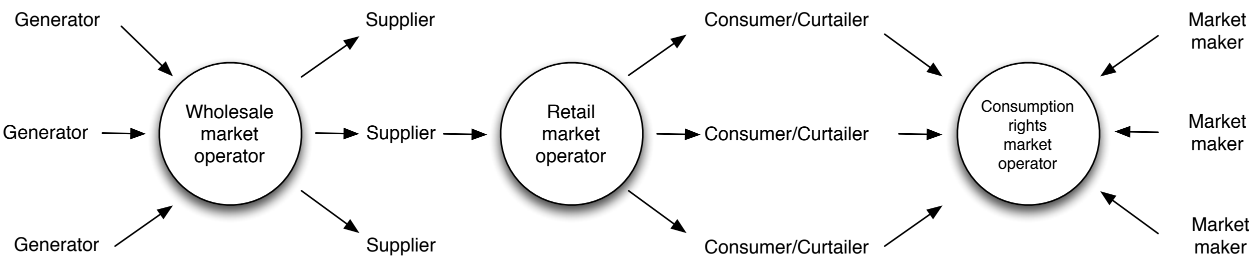

Figure 5: Electricity markets with the proposed consumption rights market added

5.1 Consumption rights market operator

The consumption rights market operator manages the market by enabling the exchange of contracts and monitoring them both prior and post execution, respectively. Prior to execution, the market operator computes a detailed (e.g., 15 minute interval) demand forecast for every participant so that there is a benchmark for curtailment contracts. The demand forecast should include factors such as day of the week, holiday, time of day, weather forecast, etc. This forecast should be openly available to each participant and any third parties they nominate. Post execution, the market operator monitors contract performance, collects fines for breaking contracts, and transfers funds between the parties. The market operator should receive a transaction fee for each executed contract.

The consumption rights market is weather dependent and will likely operate for a portion of the days during each summer or winter when conditions are extreme. This suggests that to gain economies of scale, the market operator might need to operate regionally (e.g., North America or Europe) and rely on elastic cloud computing so that a market with appropriate transaction processing capacity can be created as required rather than investing in fixed computing assets.

5.2 Supplier

The supplier buys or generates electricity and sells it in the retail market. To create a consumption rights market, the supplier must have two information systems. First, it needs a system to compute the price per MWh curve (see Figure), or an approximation thereof in tabular form, sufficiently in advance, say 12-24 hours, to enable a market to operate. The supplier must also indicate the period for which a price applies (e.g., 2:00 – 2:15pm on July 5, 2012). Second, it needs an IS to provide the market operator and other participants real-time access to the electricity meter of all consumption rights market participants.

The design indicated in the preceding paragraph suggests that there is a window of about 12-24 hours during which prices are fixed, but there might be occasions within this window when the supplier finds that set prices have varied upward considerably (e.g., sudden loss of a generator), in which case the supplier might well want to enter the market to buy curtailments.

5.3 Consumers/Curtailers

Market participants must agree to continuous real-time access to their electricity meters and abide by all contracts they execute and accept penalties for failure to meet curtailment contracts (e.g., they might have to pay double the market rate). They will likely need an IS and building control system that automates implementation of curtailment contracts (e.g., raise all thermostats by a specified temperature between a specified time period). Existing products do not provide the full capability needed for implementation of such actions on a broad scale. Consumers who can develop the ability to flexibly respond to curtailment opportunities will be able to monetize this adaptability.

Consumers will likely find it advantageous to supply third party market analysts with the details of the profits forgone under various conditions. These third parties could use such information to dynamically create coalitions to enable curtailment contracts.

5.4 Market makers

As explained previously, there might be occasions when third parties, market makers, are needed to aggregate curtailers or consumers to create tradable contracts, just as in equity markets there are operators who pool the shares of multiple participants to create marketable parcels.

5.5 Market analysts

We expect that another player will also emerge, market analysts, who will help consumers create advantageous contracts and thus make the market more efficient. They will need to access metering data and other data streams relevant to market analysis. Given the similarity of the data inputs and expertise, market markers and analysts might operate as a single firm.

6 Design validation

The next stage in this program of research is to ascertain characteristics of the market so that we can use multi-agent simulation to test operation of the market under a variety of conditions and assumptions about the various actors. We are working with a major utility, which is funding this research, to gain access to detailed data about the consumption patterns of its major customers by industry. We are also seeking data from a commercial building industry association.

7 Designing our way to a sustainable society

The designers of a DRS have a fundamental choice, market or hierarchy, and because of the lack of real time pricing across the full retail market, many have opted for various hierarchical designs. By recognizing that consumers can potentially trade their right to consume, we can design a DRS that operates as a market, potentially overcoming the "wildly complex" (Economist, 2012) current situation. Such a market is only possible because the introduction of smart meters creates a data stream that is a basis for measuring use and forecasting demand with high granularity. Smart meters enable the creation of a simple contract (an agreement to curtail use of a certain amount of energy for a specified period) with low transaction costs, because it can be implemented electronically. Furthermore, asset specificity is low (a suite of computer programs), and uncertainty is low because of the short-term nature of contracts, data granularity that enables accurate short-term forecasting and contract monitoring, and the correlation between temperatures and electricity demand. The required frequency and speed transactions, both for trading consumption rights and executing curtail commitments, favor an electronic market. Furthermore, the incentive to curtail is directly linked to short-term price expectations and provides financial rewards for those willing to find innovative curtailment mechanisms. The proposed consumption rights market strongly aligns with the logic of a market as embodied in TCE (Williamson, 1981) and market design (Roth, 2008) and is dependent on IS for its effective and efficient execution. Increasingly, as we try to solve the energy and emissions problems of a modern economy to create a sustainable civilization, we will need to design systems that comingle economic logic with the execution efficiency of IS. The proposed design of a consumption rights market for electricity illustrates the joint application of these two disciplines.

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11

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