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Common failures of demand response☆

Jin-Ho Kim [a,1], Anastasia Shcherbakova [b,*]

[a] Department of Energy and Information Technology Engineering, Kyungwon University, 65 Bojung, Sujung, Seongnam, Kyunggi 461–701, South Korea
[b] Department of Energy and Mineral Engineering, The Pennsylvania State University, 153 Hosler Building, University Park, PA 16802, United States

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ABSTRACT

Demand response (DR) programs have recently become popular means of mitigating excessive claims on regional electricity networks and providing more reliable access to electric power. Many countries have experimented with DR pilot programs and some are beginning to incorporate similar schemes as permanent elements of the electricity sector. However, DR remains an experimental technique in much of the world as programs frequently fail to meet their goals and reach their potential. This paper examines the central structural and behavioral obstacles to success of DR programs and outlines some potential solutions which could greatly improve the functionality and success of such programs in the future.

1. Introduction – a market failure in electricity

As economic development around the world advances, the demand for energy grows. With the global electricity consumption more than doubling since 1980 (an average growth of more than 3% per year[2]), claims placed on national electricity networks have experienced dramatic increases. The current challenge that more and more governments are now facing is the provision of a secure and reliable supply of electrical power to nations' industries and households as increasing population, economic growth, and spread of modern technology continue to drive up demand.

During the first half of the 20th century, when regulation took hold of US electricity markets, advances in engineering and technology lowered the cost of generating power more quickly than the growth in demand was able to increase it [1]. By 1970s, however, rising prices and declining supplies of oil and natural gas, slowing technological progress, and new environmental pressures revealed significant inefficiencies in the regulatory structure of the power market, in particular in its ability to coordinate the levels of power supply and demand, and by the end of that decade deregulation was underway.

However, the long stretch of regulation brought about a classic market failure in electricity whereby the marginal cost of electricity to consumers has fallen below its marginal cost to producers. This difference has led to a faster growth of demand than capacity additions. At the same time, as power networks become increasingly more strained, costs of new capacity rise, further lowering the prospects for infrastructure investment. Regulated markets have thus been both a cause and a consequence of reliability concerns in power provision. As long as retail electricity rates don't reflect the true marginal cost of generation, quickly growing demand levels and lagging capacity investment will continue to pose a problem.

Two recent research papers found that rise of nation states is facilitated by a policy of adaptability, which separates vested political interests from the industrial development process and ensures that dynamic industries are subjected to structural change in a timely manner [2]; and that long-term GDP growth depends on an increase in both the volume of energy consumed and its efficiency [3]. What these studies imply is that, while all countries will continue to depend on increasingly large amounts of energy to sustain their populations and grow their economies, the political actors that view power sector liberalization as a risky policy sure to result in short-term welfare loss for consumers can invariably jeopardize the continued long-term development of their states by inhibiting the restructuring process. As increasing demand for electrical power continues to push up generation costs, injecting the industry with efficiency promoting programs through the restructuring process will be important for sustained economic growth.

Although better coordination of energy supply and demand has been attempted through deregulating power markets, most of the

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* Corresponding author. Tel.: +1 814 865 9136; fax: +1 773 702 0926.
E-mail addresses: kimjh@kyungwon.ac.kr (J.-H. Kim), aus29@psu.edu (A. Shcherbakova).
[1] Tel.: +1 630 344 3604.

[2] Figures calculated using Energy Information Administration's data on World Total Net Electricity Consumption, 1980–2007.

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restructuring of the past several decades has targeted the wholesale segment of the industry. Many retail electricity providers remain constrained by price ceilings, flat rates, and other regulatory restrictions that limit the extent to which demand variations affect fluctuation of retail electricity rates, or eliminate such fluctuations entirely, thereby exacerbating the divergence of electricity production and procurement costs. Traditional methods of pricing electrical energy, such as central planner edicts or wholesale supplier auctions, have also stalled efficiency gains in electricity operations because they have precluded electricity consumers from having anything to do with price setting. As a result, demand signals have not been incorporated into retail rates, and they consistently fell short of efficient levels [4].

Electricity markets today exist in various stages of the restructuring process. Some have been liberalized completely, resembling free market in electrical power; others are only in the beginning stages; still others have not yet embarked on the restructuring journey. For utilities operating in partially restructured markets, some aspects of generation and distribution may still be regulated. This means that cost signals on the supply and demand side remain distorted to some degree. If wholesale prices are liberalized but retail prices are not, firms' ability to generate a profit from electricity sales (and consequently undertake infrastructure investment) will depend in large part on volatility of wholesale electricity prices.

In liberalized markets prices have been becoming more volatile over time (a sign of prompt response of financial markets to changing industry conditions) due to swings in the oil price, changes in the global climate, changing relationships among international trade partners, stricter environmental standards, and a variety of other developments [5]. Price volatility in regulated markets, by contrast, has been much lower, as centrally planned industries tend to revise rates less frequently and in a more measured fashion than the free market. Because this trend of price instability is expected to continue, many electricity companies will continue to face uncertain profits, which brings up another problem – that of optimal investment.

Investment in regulated electricity markets is mandated by the government, which ensures that a certain appropriate level of capacity investment occurs, increasing future reliability of supply. However, while analyzing the process of electricity restructuring, the International Energy Agency (IEA) questioned whether price signals alone can be effective incentive mechanisms for investing in electrical infrastructure in a timely manner. In general, more investment activity has been observed in areas with higher prices (i.e. greater potential revenues) [6]. To the extent that price differences stem from network congestion conditions, this pattern also suggests that investment in restructured markets tends to be more effective since it is drawn to areas of greatest congestion and, therefore, need. However, when networks are privatized, in particular networks with characteristics of natural monopolies, a strong tendency toward cost cutting also arises. [7] Furthermore, because capacity adjusts to changing demand conditions with a lag, the need for additional capacity investment may be observed only once supply security concerns become apparent. Both of these tendencies make timely investment, and therefore secure supply, more uncertain.

Since the restructuring process is likely to increase investment uncertainty in the short run, it needs to include measures to stimulate investment or reduce uncertainty. Demand response may prove to be a viable option for this end. In combination with investment incentives (e.g. production requirements, recovery provisions, etc.), demand response can reduce supply uncertainty in the short run by redistributing demand from peak to off-peak usage times or by lowering aggregate demand altogether. It can also lower utilities' exposure to price risk related to differences in volatility of wholesale and retail prices, and rebalance rates at which distributors and consumers purchase their power. In the long run, a successful restructuring process is expected to lead to balanced production and consumption costs of electricity allowed by competitive power markets, and eliminate some current causes of reliability uncertainty.

The rest of this paper is organized as follows: Section 2 presents a brief overview of demand response and offers examples of DR programs, along with their commonly expected outcomes; Section 3 discusses the main structural and behavioral challenges that cause DR programs to underperform and sometimes fail, and offers ways to address these challenges; Section 4 concludes.

2. Merits of demand response

The preferred approach to solving power network problems has traditionally been in expanding supply side efforts by installing new capacity. As incremental capacity became more and more costly, federal regulators saw a need to increase importance of efficiency and conservation in energy generation and use. This need was formalized in the Public Utility Regulatory Policy Act (PURPA) of 1978, which promoted increased use of renewable and efficient energy sources in electricity production. PURPA facilitated establishment of the first demand side management (DSM) programs in U.S. electricity markets, enabling power producers to manage electric reliability by targeting consumer demand patterns, as well as their own supply capabilities.

DSM is a very broad set of actions on the part of both consumers and utilities that includes everything from installing energy-efficient appliances and switching off unused lights, to adding local off-the-grid generation abilities, to implementing a complicated electricity pricing system in which rates vary based on time of day and aggregate power usage intensity. Demand response is a popular subset of DSM programs which relies on financial signals as main incentives for altering patterns of consumer electricity usage. These financial signals can come in the form of incentives (e.g. rebates for voluntarily curbing or foregoing power consumption during periods of particularly high demand) or penalties (e.g. encountering excessive charges per kWh during periods of peak usage). All of these policies attempt to increase reliability of electricity supply by redistributing demand and smoothing daily and seasonal peaks in claims placed on the grid.

The first demand response initiatives were targeted at large industrial entities which consumed immense quantities of electricity, principally in the form of critical peak pricing (CPP) and interruptible tariffs. Under a CPP scheme, utilities monitor power usage throughout the year and issue notifications of upcoming critical peak days on which prices are expected to spike. Companies can then forego paying high rates by shifting their usage away from critical peak days. Similarly, interruptible tariffs use advance notifications to let a firm know when power use should be curbed. In contrast to CPP, however, interruptible tariffs often rely not on reduction of usage but a temporary halt, and charge a monetary penalty in case of non-compliance.

More recently, utility companies have been giving residential customers an opportunity to get involved in demand response by signing up for time-of-use (TOU) or real-time pricing (RTP) schedules, in which the retail rate charged for electricity changes based on the time of day and year (TOU) or continually (on an hourly or more frequent basis), depending on the profile of the real-time total electricity load (RTP).

The rise of demand side initiatives as effective policy tools toward improved grid reliability is a fairly recent phenomenon. However, since the turn of the 21st century, popularity of demand response has been growing particularly quickly, with the number of organizations offering DR programs in the U.S. more than doubling between 2006 and 2008 [8]. Still, the role of demand response in the international electricity arena remains rather small, with 2008 peak load reductions reaching an average of just 2.9% in European countries and around 5% in the U.S.

The principal advantage of demand response is that it involves the consumer in a process that has traditionally been a producer's responsibility, namely ensuring reliable and uninterrupted electricity flows. If consumers can see the shape of their electricity usage profile and realize the effect this profile has on expenditures, they may be able to change their consumption behavior. By actively shifting usage to lower-cost time periods, they can participate in the price setting process directly, smoothing the network's load profiles and realizing lower electricity bills along the way. The final outcome is likely to bring not only cost savings for producers and consumers, as expensive generation of peak electricity declines, but also energy conservation and higher end-use efficiency.

There is a rather extensive body of literature analyzing outcomes of demand response programs around the world. A bulk of these studies focuses on specific programs and tries to quantify their effects on peak load reductions, changes in aggregate consumption, and expenditure [8–17]. Others are more theoretical in nature, examining how changes in electricity rates may affect consumer behavior and timing of electricity consumption [2,3,18–26].

Among the studies listed above, commonly anticipated and observed benefits of demand response include lower risks of power interruptions from lower peak loads; improved operating conditions for utility firms from increased peak-time rates, reduced marginal costs of lower peak power quantities, and ability to postpone infrastructure investment; cost savings for end users from a combination of reduced off-peak tariffs and a greater awareness of one's level and pattern of power consumption; increased spread of energy-efficient appliances; and a general increase in responsibility and prudence with regard to electricity use.

In this paper, we aim to combine theoretical and empirical findings put forth in existing literature and identify the principal structural and behavioral challenges that have been hindering the success of demand response programs.

3. Principal challenges to DR success

Even with a variety of potential gains to both sides of the market, DR programs have not yet earned a permanent spot in many of the world's power sectors. The main challenges that DR programs appear to face can be divided into three groups: consumer, producer, and structural barriers. Below we discuss each barrier category in turn, providing empirical examples and offering potential solutions.

3.1. Consumer barriers

3.1.1. Consumer knowledge

Many people around the world have very little practical knowledge about the functioning of electricity markets. A simple Google search returned more than 2,800,000 results answering the question "What is a kWh?" and informal discussions confirmed that relatively few people know what a kilo-Watt hour is; much less how many kWhs of electricity they use each month. So if consumers are not aware of their usage patterns, how can they be expected to alter them? Providers of electricity have so far not done much to ensure that knowledge levels increase. Combined with the fact that most DR programs to date have been pilot studies limited to a small number of participants, utility companies largely under-advertise the existence and potential benefits of such initiatives. As a result, participation in voluntary programs usually suffers and mandatory programs show lower than desired response levels.

What's more, limited knowledge of electricity markets has not only led to a slow development of demand programs; by suppressing the market momentum is has also slowed the development of government policies to promote DR initiatives. [16] A solution to the knowledge problem lies first a foremost with a coordinated policy effort to create a public dialogue about energy efficiency as a desired goal, along with a set of regulations that would frame demand response programs as an effective means of achieving such a goal. Once a national or state-wide dialogue has been initiated, more targeted educational efforts can be employed in altering social behavior toward energy consumption.

While increasing direct advertising and educational efforts can offset some of the knowledge problem, it will also raise the cost of administering DR programs. Combining education with mandatory participation in programs, on the other hand, might be a more cost-effective solution. Up until now, compulsory participation has only been applied to interruptible/curtailable programs. It should be expanded to dynamic pricing as well. Faruqui et al. propose a process in which utilities move their own customers from flat to dynamic rates to encourage DR participation in the Midwest ISO [23]. While this may involve a transaction cost to the utility, such a blanket approach will be much less costly than just a targeted information campaign of uncertain success. Once participation is established, information flowing from utilities to consumers is likely to have a more significant impact on behavior.

3.1.2. Availability of technology

Just as electricity users need to know the cost of the energy they are consuming, so do utility providers need to be able to precisely monitor real-time usage patterns of individual users in order to properly distribute earned financial incentives, apply correct time of use rates to electricity consumption, and so on. In many markets the slow penetration of DR technology, as well as uncertainty about its cost, has held up the spread and consequently success of demand response initiatives. In fact, this has been one of the central barriers to DR spread, particularly in the residential sector, where costs tend to be high relative to savings, as compared to commercial customers.

Spread of technology is one area in which additional regulatory policies could play a big role. The current leader in smart meter diffusion rates, Italy also has the highest retail electricity prices within the European Union (EU). In order to bring costs down, Italian policy makers devised an intensive smart meter dissemination program within the country. Given the significant cost of implementing a nation-wide smart grid, the current 90% diffusion rate would not have been possible without the government's involvement (a more thorough discussion of costs follows below). [16] Similar policies could be put in place in other international markets to promote accelerated diffusion of technologies crucial for a successful transition to market-based electricity prices and more conservative and efficient electricity use.

Ramping up development of technology and other infrastructure to advance DR will also help to establish DR as a dependable supply substitute to traditional generation, as opposed to a mere reliability supplement during emergency situations (its current principal use) [27]. This will further increase DR's popularity as alternative supply resource and augment its presence in power provision.

3.1.3. Information feeds

Seeking out price and consumption information can get very costly for consumers, discouraging them from energy-saving behavior even in presence of cost savings. Even among customers on a relatively simple curtailment plan, confusion about necessary reductions may arise during a critical peak event. We may expect, then, that having price and usage information streamed to consumers via a live feed would greatly reduce information search costs and encourage changes in consumption behavior. Simple in-home display

(IHD) devices that broadcast rate and usage information inside consumer homes have been found to do just that. Even in absence of dynamic pricing and other demand response programs, technology has been shown to affect consumer behavior with respect to electricity use. Evidence from IHD pilot programs over the last twenty years indicates that IHD use by customers on flat rate plans led to a decrease in electricity use by between seven and 14%, with the higher range applying to customers on prepayment plans [14]. Combined with variable rates, IHD-using customers also appeared more likely to respond to changes in rates [14,28].

By lowering search costs and making energy costs more transparent, IHDs make it easier for customers to adjust their consumption patterns to changing price conditions, stimulating more energy-saving behavior [20]. If more sophisticated smart grid technology is not immediately available, a network of more rudimentary IHD devices should be deployed to influence an initial change in consumption behavior.

3.1.4. Response fatigue

With or without information feeds, in order to lower expenditures, consumers on dynamic tariffs must actively respond to changing electricity prices by reprogramming electric appliances and shifting usage to periods of lower off-peak prices. The more frequently prices change, the more often the customer needs to respond to the changes. Traditionally, electricity has been considered a routine and passive purchase, since it is supplied continuously and without differentiation on quality [29]. Given this approach, a sudden need to make frequent active consumption decisions may lead consumers to grow tired of keeping track of rates and usage, and of having to reprogram appliances accordingly, a phenomenon which may fittingly be termed as "response fatigue".[3] As a result of such fatigue, some consumers may be expected to return to a default flat rate plan. Strong evidence of this behavior has been observed in experiences of Salt Lake City, Utah, and Puget Sound, Washington, where up to 98% of customers gave up TOU tariffs to return to a fixed electricity rate [30].

Because response fatigue is most likely to arise under programs where prices vary frequently, the most effective transition path from flat rates may be one in which customers are gradually introduced to market signals. The first stage could be a shift from flat to two-tiered (peak/off-peak) time-of-use rates. Once consumers familiarize themselves with the process of consumption adjustments, they can then proceed to more dynamic rate structures, such as real-time-pricing. To prevent reversion to flat rates, the transition process could be supplemented by mandatory participation requirements. Any deviation from cost minimizing behavior will then appear on the consumer's monthly electrical bill. As most people tend to be relatively price sensitive, an observed increase in electricity cost will encourage them to resume their consumption shifts to lower-priced time periods.

3.1.5. Technology cost and financing

While a demand response program would not be possible without a smart meter or another enabling device, no formal guidelines have been established as to who should be responsible for financing the installation and maintenance of such technologies. In many countries,[4] technology and other infrastructure costs were cited as the main culprits behind limited DR policy success. If it is the consumer himself who must pay for a smart meter, method and cost of financing become serious considerations. Financing rates on credit cards averaged 14.3% in 2009.[5] Using a credit card to finance the cost of a smart meter may not be economically favorable if average savings on energy expenditures fall short of the financing charges, in which case a smart meter investment would not take place [28]. Even with a 15% decrease in electricity expenditures, it would have taken an average household 16 months of energy savings to cover the cost of a typical smart meter in 2008.[6] Introducing a one-year payment plan at average credit card interest rates to finance the smart meter would extend the payback time to 18 months.[7] Given a high level of uncertainty regarding future price movements in restructured markets, a cost recovery period of this length is likely to dissuade many customers from DR participation in absence of technology subsidies.

Although undoubtedly an expensive component, a technological infrastructure is an operational necessity for demand response programs. As such, it's important to ensure that financing options, subsidies, or cost sharing agreements are available to consumers who need them. Subsidies could be provided directly, in the form of point of sale discounts or rebates, or indirectly through new construction directives and intensified roll-out programs (see, for example, Italy's efforts, described above). A limited set of direct energy efficiency rebates already exists, as outlined in the *Home Star Energy Retrofit Act of 2010*, released earlier this year [31]. In its present form, the Act offers reimbursements on household measures that increase energy efficiency, but focuses on improving insulation, replacing windows, installing efficient appliances, and similar actions. Allowances could be extended to installation of IHD devices and smart meters, the latter in areas where variable rate electricity programs are being offered or developed. Without a significant investment in technology to facilitate changes in consumption behavior, the power sector will continue to confront even higher peak generation costs. A timely investment in a more market-based approach to electricity provision, although costly in the short run, will prevent a widening gap between marginal costs of production and consumption, realizing significant savings in the long run.

3.1.6. Potential savings

DR programs depend on cost incentives to influence electricity usage patterns of end users. However, providing a cost incentive is not always enough. One must look also at the potential impact of savings on overall financial expenditures of the consumer. If electricity cost is a small percentage of consumers' total expenditure, as it tends to be in most countries, it may not be worth a customer's effort to invest in understanding time-varying prices that DR programs offer and to participate in them.

According to the Bureau of Labor Statistics, in 2009 electricity expenditures averaged 2.8% of total income in the U.S. [32], and based on a summary of demand response programs by Faruqui & Sergici [13], realized savings from demand response participation between 1996 and 2007 amounted to between two and 30 percent of total electricity expenditure. Assuming recent trends, the total potential DR savings per household then amounted to 0.056–0.84%

[3] The term "response fatigue" was first advanced by Seth Blumsack, an Assistant Professor of Energy Policy and Economics at Pennsylvania State University, during an informal discussion in February 2010.

[4] U.S. and Europe are two regions where empirical evidence found technology costs to be a significant barrier to DR. [13,16].

[5] Federal Reserve Statistical Release, "Consumer Credit," G.19, August 2010.

[6] We use $250 as an average cost of smart meter, reported for New Jersey, Ohio, and Maryland. Cost estimates for New York and Canada range between $100 and $600.

[7] Calculations based on an average U.S. household consumption in 2008 of 920 kWh/month; average cost to U.S. residential customers in 2008 of 11.26 cents/kWh; average cost of a smart meter of $250; average terms of credit at commercial banks and finance companies, for accounts assessed interest in 2008 of 13.57%; DR savings of 15% of monthly bill, which is roughly the midpoint of the 2–30% range reported by Faruqui & Sergici [13] (see next section). Consumption data retrieved from EIA, credit terms data provided by the Federal Reserve.

of total expenditures, or between $27 and $412 a year.[8] The low end of this savings range may very well be too low to induce consumers to seek information about and participate in demand response programs, but the upper range may provide sufficient incentive for changing consumption behavior.

As mentioned above, electricity by its nature tends to be a routine and passive purchase. As a counterexample, we may look at the purchasing decision for new vehicles, which account for a similar share of total annual household expenditure (2.6% vs. 2.8% for electricity).[9] If households can expect their electricity bills on average to equal their car payments, then why do we observe such different shopping behaviors when it comes to the two purchases? When shopping for a car, consumers are generally very active at seeking discounts and comparing offers of multiple sellers. The main contributing factor to such stark differences in shopping behavior is the discrete and conscious nature of new vehicle purchases, which require a large payment upfront, as opposed to a stream of smaller payments for service already consumed. This implies that the amount of active decision making that is required for purchases of electricity is significantly lower than for a purchase of a new vehicle.

Comparing electricity purchases to those of other energy sources, such as gasoline, we notice the same central difference. Although the average annual budget share devoted to gasoline and motor oil is 1/3 higher than that for electricity, at 4% of total household expenditures, it is gasoline's discrete and active purchasing characteristics, rather than higher financial outlays, that cause consumers to seek out low cost fuel stations.

Significant savings then need to be on offer in order for consumers to take advantage of demand response programs. This may mean fixing a larger gap between peak and off-peak rates to induce higher shifts to off-peak periods.

3.1.7. Satisficing behavior in switching patterns

Breukers et al. pointed out that even though effecting a change in consumer behavior is a central part of a successful DR program, analysis of social change is largely absent from existing research models [19]. The main focus has thus far been on program characteristics as contributing factors in success of demand response. One hypothesis of social behavior has been put forth by Sheth and Parvatiyar [33], who observed that consumers tend to exhibit satisficing behavior when it comes to electricity purchases. Because of the high volume of daily burdens placed on consumers' ability to process information, they prefer to simplify their decision making when it comes to routine, habitual purchases. In order for them to seek new information about alternative electricity decisions, then, they must be rather dissatisfied with their current service. So even if the potential for financial gains exists from targeting an alternative provider or program (as it may, for example, for consumers with flexible demand schedules), consumers will be unlikely to pursue these gains unless they are dissatisfied.

Support for this theory can be observed in recent statistics on switching behavior. As evidenced from preliminary results of a current study on network providers and switching patters in Germany,[10] only about nine percent of customers in the country's competitive retail electricity market have chosen to switch to a competing supplier even though they faced higher rates with the incumbent. Similar outcomes have been observed in Spain, where the program's requirement to switch to a different utility provider has rendered it unpopular [16]; France, where Tempo—arguably the world's most successful TOU program—achieved a participation rate of less than 20% of all residential and commercial customers [34]; and in Salt Lake City, Utah, where less than 0.1% of all residential customers chose to be served by the local optional TOU tariff [30]. If consumers don't find it worthwhile to switch to a lower-cost provider, they are unlikely to seek out other cost-reducing options, including participation in DR programs.[11]

Furthermore, it seems that cost considerations are often not the primary objective in electricity consumers' decision to change their service provider. Given the relatively small cost incentives – from the total income perspective – DR programs currently offer (see above), many customers end up basing their decision to switch away from or stay with the incumbent on the quality of the company and electricity being offered, rather than its cost. For example, some people strongly prefer "green" electricity; others select a provider based on the positive community impact that it exerts, etc. [20]. However, the precise conditions of the program matter as well, and the more complicated the rate structure, the more discouraged responses to rate variations will be [10].

However, even under successful programs, unintended consequences to positive behavior change have been observed. Ouyang et al. [25] note that an increase in efficient energy use in China has led to a non-trivial rebound in electricity consumption. The rebound occurs when an increase in usage efficiency lowers consumers' effective cost of energy. Lower effective costs, in turn, lead to a rise in energy purchases, offsetting some of the initial positive effects of efficiency gains.

While electricity providers could further differentiate themselves on quality, environmentalism, community orientation, and other characteristics, turning electricity into a more active purchase may prove to be tricky. One idea is to turn electrical power into a discrete purchase by making customers prepay for their service, as opposed to paying for power consumed ex post. Consumers could then rely on smart meters to track their usage and prepaid account balances, and to notify them when their balance drops below a certain threshold. However, while prepayment may get consumers to consider the cost of their electricity, it does not guarantee a change in shopping behavior. Although, even if consumers are disinclined to switch to other providers so long as they are not dissatisfied with service, providers may still be able to get consumers to transition to more market-based rate plans by providing multiple dynamic pricing options within their service area. Unintended consequences of rebounding demand, stemming from positive behavior changes, can be mitigated in part by raising electricity prices [25].

3.2. Producer barriers

3.2.1. Investment recovery

On the producer side, the main barriers to initiating a demand response infrastructure are financial. As pointed out by Wang et al., in China, as well as other countries, there are currently no formal measures aimed at facilitating the recovery of initial investment for providers, even for programs that promote conservation and more efficient electricity usage [35]. As a result, if a firm is not certain that

[8] At total average 2009 household expenditures of $49,067.

[9] Vehicles are also durable goods, which makes their purchase subject to a very different set of conditions and considerations. Since consumers do not purchase vehicles every year, we can think about annual expenditures as the average amount of principle and interest amortized during the year for the duration of the vehicle loan. The expenditure statistics then indicate that the average U.S. household in 2009 spent as much on electricity as on car loan payments.

[10] This preliminary work was briefly discussed with researchers at the Center for European Economic Research (Zentrum für Europäische Wirtschaftsforschung) in Mannheim, Germany. No citation is currently available.

[11] However, preliminary analysis of switching data among PPL customers in Pennsylvania revealed that switching rates reached nearly 35% two years following the introduction of retail choice of electricity providers. Differences in program and consumer characteristics are still being examined [Chen, Kleit, & Shcherbakova, working paper].

it will be able to recoup its initial costs, it will not invest in a program that could bring future benefits to the entire industry. This is analogous to problems observed in public good provision. In this instance we may view efficient electricity use as a public good. It reduces marginal generation costs for the industry, and is therefore non-excludable. The benefits of efficient usage are realized by the entire industry. The cost of providing the proper infrastructure to facilitate efficient use, however, typically falls on a few firms. Since no provider wants to pay to benefit others, each will be inclined to free ride on the investment of others'. In the extreme case, all providers attempt to free ride on others' efforts, and no investment takes place.

In order to ensure that investment that leads to industry-wide benefits is undertaken, the government needs to establish formal channels of investment recovery. These could include formal subsidies to the firm, for example in the form of tax write-offs, as well as a combination of mandatory customer participation requirements and monthly participation fees. Mandatory participation would in this instance ensure high subscription rates, allowing the provider to keep participation fees low while still recovering its investment in a reasonable amount of time.

3.2.2. Promotional responsibility

Along with uncertain cost recovery, substantial confusion also exists about whose responsibility the promotion of demand response programs should be. Greening [24] has pointed out that DR has been extremely slow to spread because it is unclear which segment of the electricity market should take responsibility for bringing these programs online. Is it the generation and transmission companies that should initiate such plans? Are electricity retailing companies best positioned to oversee the functioning of and participation in variable rate schemes? As the ultimate benefit from these programs would go to both the wholesale and retail segment of the industry, the author asserts that much more coordination and cooperation along the electricity supply chain is needed for successful implementation of lasting demand response initiatives.

3.2.3. Managerial incentives

A less debated but equally constraining consideration is that of managerial incentives for DR implementation. A most striking example of misaligned incentives in China is described by Wang et al. [35]. There, much like in the rest of the world, a manager's performance and compensation is unambiguously linked to firm profitability, so if a public electricity firm becomes less lucrative, a manager's job and reputation may be at stake. Given the fact that demand response programs are designed to lower demand during the highest usage periods, when electricity is most expensive, lowering peak usage may actually result in a loss of revenue for the firm. If profit margins on peak generation are lower than they are on off-peak generation, which is typically the case given extremely high costs of running peaking plants, a loss of revenue will occur unless the ratio of changes in off-peak to peak consumption exceeds the inverse ratio of their respective marginal revenues.[12] Unless this condition is achieved, a manager will have no incentives to invest in demand response; quite on the contrary, he may be inclined to increase power usage levels at all times so as to ensure a healthy cash flow for the company [35].

One way of overcoming this disincentive problem is to index managerial remuneration not only to financial performance, but to a combination of utility's fiscal success (for instance, a separate evaluation of revenues and average generation costs, the latter of which will decline as more peak demand is shifted to off-peak periods) and technical reliability. Another solution would be to introduce non-financial obligations, similar to renewable portfolio standards which require firms to produce specific amounts of renewable energy. Since managers effectively dictate the direction of the company they oversee, aligning managerial incentives with DR development will do a great deal to incorporate market-based price signals into power sector management.

3.3. Structural barriers

3.3.1. Program structure (rates, technology, etc.)

Developing sophisticated economic demand response programs with complex rate structures has over the years proven to be very difficult. While some service areas[13] still rely on emergency DR programs, many regions have tried, with mixed success, to devise appropriate variable rate structures and financial incentive schemes to effect sizeable consumption shifts across congestion periods. Suboptimal rate structures quickly lead to underperformance and failure of these programs.

To borrow another example from China, Wang et al. [35] conjectured that DR success in the country has been held back by suboptimal pricing strategies. The country's present policy dictates that the average electricity price in areas where TOU tariffs are utilized must equal the average electricity price in areas with no temporal differentiation. [35] This means that any reduction in total electricity consumption will result in a loss of revenue for supplying firms and, in combination with the managerial incentives structure, any motivation to invest in DR initiatives will be eliminated.

Other DR pilots suffered poor results when differences in time of use rates set across various usage periods turned out to be either insufficient in inducing any usage shifts across pricing periods (Idaho and Missouri), actually increased the total electricity cost to consumer (Washington), or resulted in profit losses for large industrial firms with peak cost savings falling short of foregone revenue due to reduced peak-time operations (Spain) [13,16].

In addition, variable rates must account for many social, economic, and geographic characteristics of the area in which they are being implemented. For instance, studies have shown that price elasticity of substitution[14] tends to be higher in areas where average education levels are higher, and in warm climates, where households operate more discretionary appliances like air conditioners [13].

Analyzing empirical evidence, Cappers et al. [8] find that although nearly two thirds of all demand response programs in the U.S. in 2008 employed time-based rates in their structure, these programs achieved only 7% of total coincidental peak load reduction; the remaining 93% was due to incentive-based programs that employed direct rebates for demand curtailment. Faruqui & Sergici confirmed that TOU tariffs have amounted to some of the smallest reductions in peak demand across all tested rate structures [13]. On the plus side, customers subscribing to simplified curtailment programs, such as California's CPP program, exhibited good responses to the state's announced critical events in 2004 [15].

[12] $\Delta TR = \Delta Q_{op} \times MR_{op} + \Delta Q_p \times MR_p$. Since $\Delta Q_p < 0$, avoiding a loss in total revenue ($\Delta TR \geq 0$) necessitates $\Delta Q_{op} \times MR_{op} \geq \Delta Q_p \times MR_p$ or $\Delta Q_{op}/\Delta Q_p \geq MR_p/MR_{op}$.

[13] Midwest ISO is one of service area in the U.S. which lacks economic demand response programs [23].

[14] Proportional shift between peak and off-peak demand, given a 1% change in price.

Because consumer response to dynamic rates depends on a multitude of regional and demographic variations, such as incomes, education levels, climate conditions, and so on, devising an appropriate rate structure should be an ongoing process. Variable rates should be continually adjusted to maximize response levels until congestion-based price difference are great enough to induce sizable shifts in usage. Once an appropriate rate structure is set, regulators need to continue to account for seasonal, industry, and macroeconomic changes. Regular revisions will ensure that rates of response of usage to price changes continue to remain high, smoothing out intertemporal demand peaks, reducing network congestion, and lowering generation costs.

3.3.2. Regulatory (restructuring) process and policy support

More broadly, however, the ongoing process of restructuring electricity markets has focused on sweeping industry-wide changes, and for this reason has not been particularly accommodating toward DSM programs, including DR. In its 2006 report, the Federal Energy Regulatory Commission (FERC) found that the amount of demand side resources utilized by a North American electricity market was negatively correlated with the degree of restructuring of that market [17]. The most highly deregulated markets, therefore, experienced the greatest declines in their availability of demand-side resources. A similar finding was obtained by the International Energy Agency in 2000, which concluded that power sector reforms do not appear to remove barriers to demand side management designs [35].

Separation of wholesale and retail segments of the power market in China exacerbated barriers to demand response simply because the country's electricity industry's reform process is incompatible with the goals of DR [35], while European DR stalled because of the region's high focus on energy market liberalization [13]. Similar outcomes transpired during the restructuring of the Electric Reliability Council of Texas (ERCOT), which prior to deregulation made significant advances in the field of demand response. Having accumulated nearly 3500 MW of electrical power reserve loads for managing reliability of energy provision, ERCOT lost 3000 MW (86%) of this planning reserve in 2002 with the introduction of retail competition and termination of all existing tariffs [17].

While some research produced evidence that industry restructuring and federal policy support has helped to expand the DR industry up through 2008, leading to product and service innovation [8], other studies suggest that degree of participation depends highly on market design and in most cases regulatory intervention, such as development of targeted rather than broad restructuring procedures, is needed in order to sustain DR programs in reorganizing markets [17]. It seems that government regulation still has an important role to play, even in liberalized power markets, in ensuring timely investment in demand side management, and promoting DR as a competitive method of alleviating excessive burden placed on existing supply networks and of balancing electricity supply and demand.

4. Conclusion

In this paper we examined the most common social and behavioral challenges currently faced by demand response programs. Although its popularity has grown over time, demand response still plays a relatively small role in increasing efficiency of energy use. The power sector's restructuring process, in its path to free market outcomes, often fails to encourage development of the same innovative programs that can facilitate the transition to a free-market structure (such as demand response programs). In fact, by increasing exposure to price risk and revenue uncertainty, it can bring about perverse outcomes, such as capacity underinvestment and political protectionist sentiment. Without restructuring, however, the power sector will continue to face escalating costs of peak generation, insufficient revenues from administered prices, completely decoupled from supply and demand effects, and a deteriorating supply security. During the volatile transition period from regulated to competitive market, demand response initiatives can be an effective tool to link production and consumption costs to supply and demand considerations, and reduce network congestion by rebalancing demand patterns.

Increasing the success of these programs is therefore an important step in ensuring a smooth transition to market-based power provision and increased energy supply reliability in the future. Empirical evidence reveals that the most common obstacles to DR success can be categorized into consumer, producer, and structural barriers, and in many cases relate to either lack of knowledge, availability and cost of technology, or an incompatible reform process. Although implementing fruitful DR policies and programs can come at a non-trivial cost to regulatory agencies, the gains afforded by implementation – including improved profitability and operating conditions of utilities, and increased use efficiency and cost savings of consumers – are likely to be sizeable.

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