ICELAND SCHOOL OF ENERGY
REYKJAVIK UNIVERSITY

Inciting Residential Demand Side Participation in Electricity Markets: Three Elasticity Issues That Stand in the Way

Sam D. Bailly

Thesis of 60 ECTS credits
Master of Science (M.Sc.) in Sustainable Energy Science

April 2018

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5 / 1 / 2018

Date

Sam D Bailly

Sam Denison Bailly
Master of Science

I dedicate this thesis to my mother.

Að hvetja til þátttöku í íbúðarhúsnæði í rafmagnsmarkaði: Þrír elasticity tölur sem standa í vegi

Sam D. Bailly

Apríl 2018

Útdráttur

Að taka þátt í þátttöku þátttöku eftirspurnar og dreift orkulindir (DER) á raforkumörkuðum, er mikilvægt að snjalla grannleiki. Hins vegar hvetur eftirspurnarsíðan að neytendur séu teygjanlegar á heildsöluverði sem breytilegt er eftir tíma og staðsetningu. Í meginatriðum meta bandarískum íbúðarhúsnæðismarkaðs neytenda, finnst mér að þrír aðal "mýktarmál" hamla neysluverðs mýkt. Grundvallaratriði "mýktarmál" er að neytendur fá ekki tækifæri til að vera gjaldþrota þar sem mikill meirihluti heimila heldur áfram að kaupa rafmagn á meðaltali flatrými, sem ekki merkir kostnað og gildi fyrir neytendur. Annað "teygjanlegt mál" snýst um vanhæfni neytenda til að vera verðlækkandi þegar verða fyrir síbreytilegu verði. Þriðja "mýktarmálið" fjallar um skort á því að neytandinn sé reiðubúinn til að vera gjaldþrota og nærvera tilviljun neytenda við stjórnun á rafmagnskostnaði. Með því að leysa "mýktarmál" þarf að neytendur verði fyrir heildsölumarkaðsaðstæðum, vera með tækni sem auðveldar verðsvörun og að bæði fyrrverandi og síðari séu í raun gert fyrir þau. Þetta mun líklega þurfa tvíþætt lausn. Mikil stefnaaðgerð þar sem þjónustufyrirtæki þurfa að breyta sjálfgefnum smásöluhlutfalli í einn sem er öflug og verðmæt byggð og inngangur nýrra orkufyrirtækja frá þriðja aðila (ESCO), sem útbúnaður neytendur með sveigjanlegum eignum, þar sem gjaldskrárin virði .

Inciting Residential Demand Side Participation in Electricity Markets: Three Elasticity Issues That Stand in the Way

Sam D. Bailly

March 2018

Abstract

Engaging demand side participation and distributed energy resources (DERs) in electricity markets, is imperative to smart grid adoption. However, stimulating the demand side requires that consumers are elastic to wholesale prices that vary by time and location. In broadly evaluating US residential retail consumer elasticity, I find that three primary "elasticity issues" inhibit demand side participation. The foundational "elasticity issue" is that residential consumers aren't given the opportunity to be price responsive, as the vast majority of households continue to purchase electricity on averaged flat-rates, that fail to signal cost and value to consumers. The second "elasticity issue" pertains to consumer's inability to be price responsive when exposed to ever changing prices. The third "elasticity issue" addresses the lack of consumer willingness to be price responsive, and the presence of consumer apathy in managing their electricity costs. Solving the "elasticity issues" requires that consumers be exposed to wholesale market conditions, be equipped with technologies that make price response easy, and that both the former and the latter are effectively done for them. This will likely necessitate a twofold solution. A significant policy intervention whereby utilities are required to change the default retail rate to one that is dynamic and value based, and the entrance of new third-party energy service companies (ESCO), that outfit consumers with flexible assets and DERs, where the tariff signals value.

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First, I would like to acknowledge Ewa Carlson for her supervision and guidance. Her instruction was invaluable in shaping my arguments, and tailoring the scope of my thesis. Thank you for your unwavering commitment.

I would like to thank Environmental Defense Fund, in particular Michael Panfil and Bryony Worthington, for directing my attention to the demand side of electricity markets. My time with EDF inspired this thesis.

Finally, I'd like to thank my family and friends. Your support is absolute.

Contents

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List of Acronyms and Symbols

401(k)	Tax exempt retirement savings plan
AMI	Advanced Metering Infrastructure
CAPEX	Capital Expenditures
CAISO	California Independent System Operator
C&I	Commercial and Industrial
CPP	Critical Peak Pricing
DER	Distributed Energy Resource
DR	Demand Response
DSR	Demand Side Resource
DOE	Department of Energy (US)
DSIP	Distribution System Implementation Plan
E3	Energy and Environmental Economics, Inc.
EDF	Environmental Defense Fund
EIA	Energy Information Agency (US)
EPA	Environmental Protection Agency (US)
EPRI	Electric Power Research Institute
ESCO	Energy Service Company
EV	Electric Vehicle
FERC	Federal Energy Regulatory Commission
FVT	Full Value Tariff
ICAP	Installed Capacity
IHD	In-Home Display

IOU	Investor Owned Utility
ISO	Independent System Operator
IPP	Independent Power Producer
kWh	Kilowatt-hour
LBMP	Location Based Marginal Pricing
LMP	Locational Marginal Pricing
LSE	Load Serving Entity
NYISO	New York Independent System Operator
OASIS	Open-Access Sam-Time Information System
PVRR	Present Value of Required Return
QF	Qualifying Facility
RTO	Regional Transmission Operator
RTP	Real Time Pricing
RDSI	Renewable and Distribution System Integration
SGIG	Smart Grid Investment Grant
SMUD	Sacramento Municipal Utility District
TOU	Time of Use
TVR	Time Variant Rate
$/kW	Dollar per kilowatt
$/kWh	Dollar per kilowatt-hour

1. Introduction

The monumental task of decarbonizing the power sector in response to climate change is riddled with challenges. One of the primary challenges is creating an energy system that is capable of decarbonizing. Today's energy systems are characterized by centralized, large-scale, fossil fuel dependent power plants, whereby supply follows the peaks and troughs of demand. The majority of U.S. electricity supply, particularly that which meets system peaks, is carbon intensive, contributing roughly 29% of the country's total greenhouse gas emissions (2015 data) (EPA, 2017). The low carbon energy system of tomorrow, necessitated by the correlation between greenhouse gas emissions and climate change, is one characterized by large quantities of renewable generation and distributed energy resources (DERs).[1] However, the most prevalent and presently economic low carbon resources, wind and solar, are variable resources, and therefor require a flexible and intelligent energy system to effectively operate (Faruqui, Hledik & Palmer, 2012). Ultimately this sort of energy system, generally referred to as the "smart grid," requires demand side participation that is incentivized to be responsive to market conditions. It is this need for demand side participation that gives rise to the significance of retail electricity rates, and the role retail rates play in incentivizing response, inherent to the adoption of "smart grids." However, the relationship between retail electricity rates and stimulating demand side participation is marked by a number of challenging issues in itself. It is these challenges, particular to incentivizing and enabling electricity consumers to become active participants in electricity markets, that this thesis takes issue with.

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[1] This thesis defines DERs as assets that include distributed generation, demand response, energy efficiency, and storage (including EVs).

In theory, retail electricity rates have a determinant effect on how participants interface with the energy system, and ultimately should have a determinant effect on the construction of the grid. In most markets for goods and services, prices influence consumption decisions, and changes in consumption decisions influence production decisions. However, for this relationship between price, consumption, and production to remain true, prices must in fact influence consumption decisions. In other words, consumers must be price elastic. In the case of electricity markets, particularly in regard to the residential retail segment, short-term changes in the price of electricity have little effect on consumption decisions, and therefor fail to influence production decisions that determine where and when electricity is generated and transported. Given that electricity is not economically storable, fluctuations in the supply and demand of electricity produce volatile prices (peaks and troughs) (Allcott, 2012). Additionally, transporting electricity from power plant to consumer, is subject to the availability of transmission and distribution capacity, creating disparities in the price of electricity from one location to another. To efficiently utilize grid resources, particularly as more variable renewables come on line, consumption decisions need to be influenced by changing grid conditions.

Prices convey information, and should express cost and value to market participants, allowing participants to make informed decisions to minimize cost and maximize value. For prices to convey this information, they need to accurately represent the marginal costs of serving load at a given time and place. Historically, and into the present, retail rates have done an exceptionally poor job of passing on the variance of costs (distinguished by time and place) to customers in the form of electricity prices. For a myriad of reasons, utilities have largely averaged costs to create uniform, non-variant electricity prices for their customers. Thus, wholesale market conditions, that vary considerably over time and space, remain unknown to consumers. Without exposure to price variance, the value of DERs that would otherwise leverage price volatility and locational value, is significantly undermined. Ergo, customers lack incentive to alter their consumption behavior to control costs, and to adopt DER technologies that would allow them to better do so.[2]

Ultimately this becomes a matter of demand interfacing with price, or rather how changes in price affect demand, defined in any introduction to economics textbook as the "price elasticity of demand." As I'll demonstrate over the course of this thesis, stimulating demand side participation and smart grid adoption through retail rates, encounters three primary "elasticity issues" that undermine this objective. The *opportunity* to be price responsive, what I'll refer to as the "1st Elasticity Issue." The *ability* to be price responsive, the "2nd Elasticity Issue." And consumer *willingness* to be price responsive, the "3rd Elasticity Issue."

The "1st Elasticity Issue" addresses the challenges that surround the *opportunity* to be price responsive to market conditions. This issue is where it all begins, and is particular to the availability of rates that are dynamic and value based, and send accurate price signals that make price response a possibility. Within the "1st Elasticity Issue" is the requisite of Advanced Metering Infrastructure (AMI), necessary to express price and consumption information both to the load serving entity (LSE) and to the consumer. The "2nd Elasticity Issue" pertains to the consumer's *ability* to be price responsive, and the ease of price response. This is largely determined by the availability of automation technology such as smart thermostats, and smart consumer appliances, as well as the ability to leverage DERs to take full advantage of a dynamic

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[2] When rates are designed such that marginal costs are accurately accounted for, the cost of DERs and technologies that enable/automate demand response are able to compete against the price of electricity (Energy and Environmental Economics, Inc. 2016). In other words, if the marginal cost of certain DERs (for a particular residence) consistently outperform the marginal cost of electricity coming from the grid, the DER solution is more economical.

and value based rate. In short, how flexible can a consumer be, while posing limited inconvenience to the consumer? The "3rd Elasticity Issue" concerns the consumer's *willingness* to be price responsive, and is ultimately a question of consumer apathy. Do consumers care enough about controlling their electricity costs to take action that equates to enrolling in a dynamic and value based rate program, and to acquire assets that allow them to leverage their rate?

Solving the "1st Elasticity Issue" is fundamental to making the transition from today's predominantly centralized and fossil fuel dependent energy systems, to decentralized, DER rich, low carbon energy systems. Therefor, a significant portion of the text will be spent treating retail rate design, and the implications of rate design. A number of time-variant rates (TVR) have been introduced over the years, but creating the *opportunity* for successful price response, requires the right price signal, and therefor the right rate design. The energy system of the future requires rates that embody cost causation principles that reflect both present and future marginal costs in respect to time and location.[3] This thesis pays particularly close attention to the rate design proposed by Energy and Environmental Economics, Inc. (E3) in response to the State of New York's Department of Public Service's *Staff Whitepaper on Ratemaking and Utility Business Models*, and New York's "Reforming the Energy Vision" Program. E3 dubbed their tariff the "Full Value Tariff" (FVT), and fittingly so. The FVT offers perhaps the best solution to date to follow cost causation principles, and to provide a rate that fairly assigns cost and value in the retail market. The FVT incentivizes retail consumers to be price responsive and to take advantage of DER technologies in relation to actual market conditions. Thus, providing

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[3] Cost Causation Principles- Cost causation entails assigning costs to those responsible for incurring the cost, and should thus be incorporated into the electricity prices each customer receives. Given that these costs vary greatly based on time and location, so to should the price (Gordon and Olson, 2004).

consumers with the right *opportunity* to manage electricity costs, equating to system wide improvements in resource allocation and market efficiency.

While this type of tariff makes the business case for DERs and enabling/automation technologies ("flexible assets"), the effectiveness of this type of rate, both in terms of customers successfully controlling costs, and yielding efficient market outcomes, is inherently dependent on customers acquiring these "flexible assets." Effectively responding to price signals, as numerous time-variant-pricing pilots suggest, requires that consumer response necessitate little action or change in behavior by the consumer. If the 1st and 2nd "elasticity issues" can be solved through the availability of dynamic and value based rates, paired with "flexible assets," the relationship between rate design and stimulating the DER market should be solved. Consumers will seek DER solutions to take control of their energy costs, and to benefit from the variance in the price of electricity. With this, consumers become participants in energy markets, creating a bi-directional energy system that optimizes resource utilization (both generation and transmission), better integrates variable renewables, and ultimately makes an efficient smart grid a reality.

However, this assumes that consumers are rational economic thinkers. The study of behavioral economics tells us that we can't so easily make this assumption. Thus, I address the "3rd Elasticity Issue," the predicament of economically irrational or "unmotivated" consumers. By applying behavioral economics and extrapolating similar market outcomes, this thesis makes the argument that the availability of dynamic and value-based rates, as well as technologies that make rate utilization easy and effective, will not directly equate to widespread enrollment in "good" rates, and the take up of DERs. Despite the opportunity for significant cost savings, a number of cognitive biases will prevent consumers from seeking out cost management opportunities, even with low barriers to do so. For this reason, I propose two enablers for further study, that will likely be necessary for successful and widespread enrollment in dynamic and value-based rates, complimented by DERs. The first being a drastic policy measure requiring utilities to change the default rate to a design similar to the FVT, with an opt out provision. With this, the entrance of new DER/ESCO business models will be necessary to equip retail consumers with "flexible assets" that allow them to effectively utilize this type of sophisticated rate. In using policy to enroll customers on rates that signal value, the private sector will mobilize to extract a portion of value where it exists, and in doing so make consumers effective participants in energy markets. In solving the three "elasticity issues," the demand side of the market is activated, in turn making an intelligent, flexible, and low carbon energy system possible.

The contents of this thesis will be provided in the following order. The topic of this thesis specifically pertains to the retail rate "elasticity issues." However, the objective of addressing this topic is to assist in removing barriers to smart grid adoption. For this reason, Chapter 1. will provide a brief explanation of tomorrow's energy system, the smart grid. Before proceeding with the "elasticity issues," Chapter 2. will cover the beginnings of electricity in the U.S., providing context on how today's energy system and wholesale markets, came to be. This is particularly important given that the marginal costs that retail rates should follow, originate in efficient, competitive wholesale markets. Following an explanation of the wholesale market, I'll cover the relationship between wholesale market prices and retail rates. Next, Chapter 3. addresses the implications of retail rate design and identifies the cause and effect of today's flat rates and the market failures born out of rates that depart from marginal costs, and ultimately inhibit demand side management. Next, Chapter 4. will address alternative rate designs that move closer to following marginal costs, but ultimately fail to provide a rate design that satisfies the "1st Elasticity Issue." Within this chapter, I cite numerous time-variant rate pilots and programs, and corresponding studies on price response. Here, I introduce the "2nd Elasticity Issue," making the distinction between consumers with enabling and automation technologies, and those without, in respect to price response capability. In Chapter 5. I revisit the "1st Elasticity issue," in order to suggest E3's FVT as a suitable tariff to provide accurate, marginal cost based prices that incentivize both demand response and the adoption of DERs, where the market signals value. In Chapter 6. I make the reasonable assumption that both the 1st and 2nd "elasticity issues" are solvable, and turn to the "3rd Elasticity Issue;" the predicament of consumer willingness to switch to a rate such as the FVT, and to adopt technologies that maximize value and the ability to manage costs. Here I suggest a two-fold solution; the need for policy makers to change default rates to something akin to the FVT, and the entrance of third party DER/ESCO businesses to drive change (equip consumers with flexible assets) in the absence of motivated consumers. Before offering my conclusion in Chapter 7., Chapter 6 discusses the challenges and opportunities in implementing this solution.

1.1. A Brief Explanation of the Smart Grid

Today's unidirectional power systems, transmitting at distance, without participation from the demand-side, have little ability to decarbonize (EPRI, 2011). EIA, 2016 statistics, indicate that natural gas and coal fired power plants respectively make up roughly 33.8% and 30.4% of the U.S. energy mix. Low carbon resources, nuclear and renewables (primarily hydro and wind) respectively make up 19.7% and 14.9% of the generation mix (EIA, 2017). Under today's technical and economic conditions, the best pathway to decarbonizing is to increase wind and solar output, maximize energy efficiency, and drastically expand DER adoption. However, significantly increasing the share of wind and solar, both intermittent resources, while simultaneously increasing the share of resources at the grids edge, requires intelligence and flexibility to manage and utilize these resources (Joskow, 2012). As policy makers increasingly recognize the need for emissions reductions through renewables and efficiency, as well as improving reliability and energy independence, smart grid initiatives continue to develop around the world. The U.S. is expected to invest between $238-$476 billion in smart grid projects by 2030 (EPRI, 2011). The EU is forecasted to invest €56 billion by 2020 (Pike, 2011). As of 2011, the U.S. Department of Energy funded 99 smart grid investment grants (SGIG), 32 smart grid demonstration projects, and 9 Renewable and Distributed System Integration (RDSI) projects. The EU, as of 2011, had initiated 219 projects. (European Commission & U.S. Department of Energy, 2012).

At a foundational level, smart grids require widespread deployment of smart meters that enable transparency and communication of grid conditions for both consumers and operators, and to make consumer response (flexibility) through dynamic rates, possible (Joskow and Wolfram 2012). Electric Power Research Institute (EPRI) defines the smart grid as, "the modernization of the electricity delivery system so that it monitors, protects, and automatically optimizes the operation of its interconnected elements – from the central and distributed generator to the high voltage transmission network and the distribution system, to industrial users and building automation systems, to energy storage installations, and to end-use consumers, and their thermostats, electric vehicles, appliances, and other household devices" (EPRI, 2011). In respect to this thesis and the intersection between retail rates and the "smart grid," it is the consumer side of the "smart grid" that is of particular interest. By activating retail consumers, power systems become bi-directional, whereby residences can both curtail load, source their own generation, and provide generation back to the grid through DERs. Below, Figure 1 provides a general schematic of smart grid components, and the bidirectional flows between operators and end-users with DERs at the grids edge.

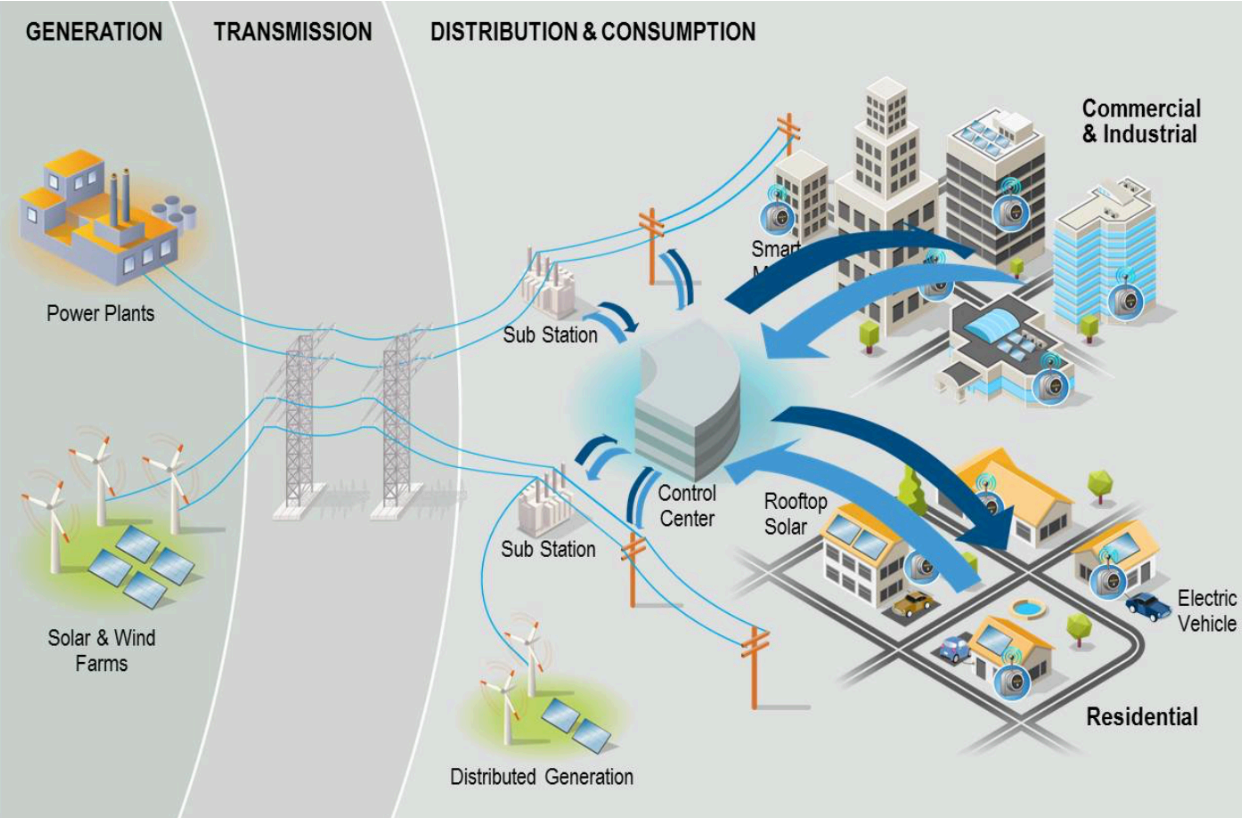

Figure 1: Smart Grid Illustration (Trilliant, 2017)

DERs represent a broad class of assets that bolster demand side management, empowering the consumer by providing alternatives to utility services, improving grid resiliency by reducing reliance on centralized power sources, decreasing the need for new build generation and transmission, and reducing overall dependence on fossil fuel generation (Energy and Environmental Economics, Inc., 2016).[4] DERs can be both community based (community solar field or aggregated demand response) or on consumer premise (behind-the-meter). This thesis is particularly concerned with DERs on consumer premises. New York System Operator (NYISO)

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[4] On site (behind-the-meter) diesel generators are also a form of DER. Therefor it can't be explicitly stated that all DERs reduce fossil fuel dependent generation.

defines DERs as “a resource, or a set of resources, typically located on an end-use customer’s premises that can provide wholesale market services but are usually operated for the purpose of supplying the customer’s electric load. DERs can consist of curtailable load (demand response), generation, storage, or various combinations aggregated into a single entity” (NYISO, 2017).

When DERs are appropriately valued (through “good” rate design), the platform for consumer engagement and participation is created, enabling the demand portion of the smart grid. In the words of the esteemed energy economist Severin Borenstein, “the failure to incorporate demand flexibility has imposed unnecessary generating plants, production costs and environmental harm on society. An electricity system that permits adjustments on both the supply and demand side will improve efficiency, reduce costs, and benefit the environment” (Borenstein, 2005). As I move forward in addressing the “elasticity issues” that undermine the adoption of dynamic and value based rates, the goal of stimulating the demand side of the smart grid, should be kept in mind. Before proceeding with retail rates and the “elasticity issues,” I’ll next provide necessary background on how today’s energy systems and markets came to be in the United States, and illustrate the origins of marginal cost in wholesale markets, before shifting attention to retail rates.

2. But First, the Wholesale Market

The first objective of this thesis is to identify and review the type of retail rate design needed to make demand side participation a possibility. Retail rates that make marginal costs transparent by sending accurate price signals, reflective of real-time market conditions, are fundamentally necessary in creating the opportunity for efficient demand side management, for both consumption and investment decisions. At its most basic level, connecting retail rates to efficient wholesale prices that change in respect to time and location, allows for accurate price signals, indicative of marginal costs (Borenstein, 2005). Solving the “1st Elasticity Issue” is about giving consumers the opportunity to be price responsive to information that appropriately conveys cost and value. Thus, efficient pricing, beginning in wholesale markets, must be accurately expressed in retail markets, to stimulate demand side management and to create an environment conducive to the development of an intelligent and flexible energy system.

Today in the United States, two types of wholesale markets exist. Traditional, noncompetitive wholesale markets, and competitive wholesale markets operated by an Independent System Operator (ISO) or Regional Transmission Operator (RTO). The competitive wholesale markets run by ISOs and RTOs are highlighted below, in Figure 2. The white areas of the map represent traditional, noncompetitive markets.

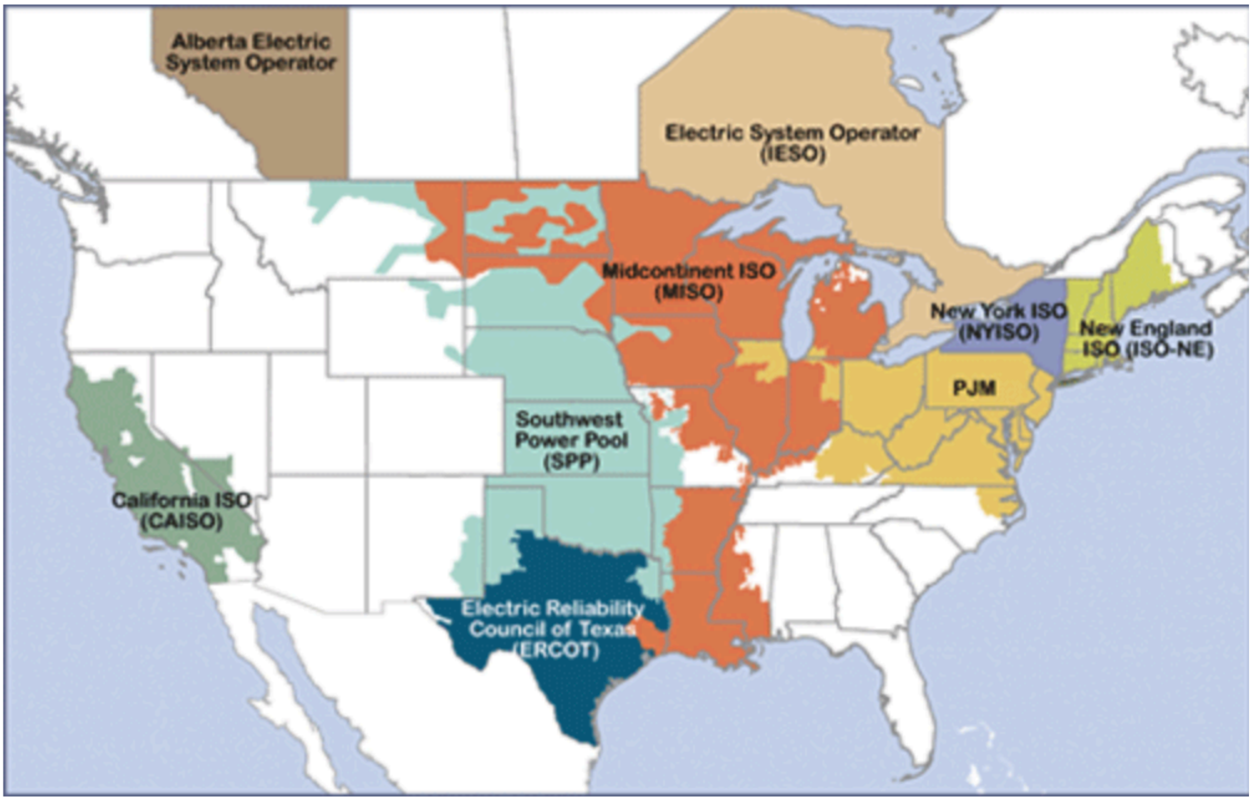

Figure 2: Map of ISO and RTO wholesale market regions in the US and Canada (FERC, 2017)

The establishment of competitive wholesale markets, and distinctions between competitive and traditional markets has had significant implications for the understanding of retail rate design. The departure from traditional wholesale markets using estimated marginal costs, to competitive wholesale markets with transparent and volatile prices, unveiled the extent of distortions between flat retail rates and the actual marginal cost of electricity (Joskow & Wolfram, 2012). Given the fluctuations in the marginal cost of producing electricity, it became clear that the opportunity cost of consuming electricity varies in step with price fluctuations (Borenstein & Holland, 2005). While some economists, particularly Alfred Kahn, had long been aware of such distortions in regulated utility markets (including airlines, telecommunications, etc.) and had advocated for simple forms of time-variant prices well before deregulation, the advent of competitive wholesale markets with volatile real-time prices, illustrated that simple peak and off-peak prices, were still highly averaged (Kahn, 1970). Economists began to recognize that the closer retail rates reflected competitive wholesale markets prices, the greater market efficiency and social welfare would be (Joskow & Wolfram, 2012). Today, with DERs and the smart gird requiring rates that signal value and cost, aligning retail rates with competitive wholesale markets has never been more relevant. Given the importance of competitive wholesale markets revealing the true fluctuations in the marginal cost of serving load from one time and place to another, and providing the foundation for retail rates to follow marginal costs, it's worth exploring how these markets came to be, and how they function.

2.1. Traditional Markets, from Past to Present, and the Coming of Competition.

Around the turn of the 20th century, with the advent of alternating current (AC) providing the ability to effectively transmit power at distance, the industry quickly recognized the economic benefit of large centralized power systems (The University of Texas at Austin Energy

Institute, 2016). While building large power plants offered economies of scale, financing large projects presented barriers to industry. Ultimately these financial barriers would lead to only a small number of holding companies owning the majority of investor owned utilities (IOU) (The University of Texas Austin Energy Institute, 2016). Thus, the economic benefit of large scale, centralized power production, inherently bred natural monopolies.

This would become the long-lasting model of single ownership of generation, transmission, and distribution (vertical integration) that characterizes "traditional" markets. In this structure, all or near all components up to the point of delivery, are owned and operated by the same utility. Consequently, competition is largely absent from the market, thus requiring rate of return regulation, and the use of cost-based rates to protect the interest of consumers (Joskow, 2006).

Under this framework, the regulator permits the utility to set electricity prices at rates that allow them to make a "reasonable" return on investment, based on their costs to provide the service. Under this structure, regulation acts as the means of ensuring that "costs are efficient," as oppose to the market making this determination (McDermott, 2012). To do so, regulators determine the allowed price by calculating the utilities cost of service, plus a reasonable return (McDermott, 2012). The figure is calculated as follows.

$$TR = TC = [RB - D]ROR + OE + d + T \tag{1}$$

$Where$:

$TR = \ total\ revenue$
$TC = \ total\ cost$
$RB = \ rate\ base\ or\ value\ of\ capital$
$D = \ accumulated\ depreciation$
$ROR = \ rate\ of\ return$
$OE = \ operating\ expenses$
$d = \ annual\ depreciation\ cost$
$T = \ taxes$

Ultimately this framework breeds inefficiency and makes significant deviations away from the actual marginal costs of production. Rate of return is calculated via an "averaging of historic costs incurred by the company over many time periods" (Allison, 1985). Given that firms seek to maximize profits (at least regarding IOUs) utilities are inclined to overcapitalize and unnecessarily increase their asset base to yield greater allowed return, and then cut costs after the calculation has been made to maximize return, resulting in the set price to be set above actual marginal cost of production (Allison, 1985). Even when firms do not wish to overestimate their costs, the variability of input costs, from financing to fuel, is such that averaging is sure to stray from marginal costs, up or down, resulting in inefficient pricing. In respect to dynamic retail rates, not only are the marginal costs that dynamic rates seek to replicate, hidden, but the idea of dynamic rates (reducing peak demand) runs counter to a business model predicated on capital investment, to drive growth (Borenstein, 2009). Once again, the departure from the "traditional" market structure is seen as laying the foundation for dynamic rates, and therefor I turn my attention to the coming of competition, and the function of competitive wholesale markets.

As the electrification of America continued throughout the first half of the 20th century, both the public and private sector soon recognized the inextricable link between electricity and prosperity. With that came a number of policies enacted to spur the ubiquity of electricity across America. For many years, wholesale markets remained a combination of IOUs, municipal, state, and federally owned utilities. However dramatic change in the structure and regulation of wholesale markets was born out of the early 1970s energy crisis. American leadership became hell-bent on ensuring energy security, and decreasing dependence on foreign oil supply. The most impactful piece of legislation coming out this movement, in terms of moving power markets towards competition, was the Public Utility Regulatory Policies Act of 1978 (PURPA). To ensure adequate capacity, PURPA brought about state driven emphasis on "efficient cogeneration and small scale renewable generation. FERC's role was to issue regulations for the program and certify that qualifying facilities (QFs) met statutory requirements" (FERC, 2015). The rate to be paid to QFs by utilities was established at the state level by the avoided cost that the utility would otherwise incur to generate the electricity themselves. In states where the avoided cost rate was set relatively high, large quantities of not-utility generators began selling to utilities. FERC further developed this idea in 1988 by allowing states to set auction based rates. It was this development of generation outside of the tradition vertical model that introduced the idea of independent power producers (IPP), and the beginnings of competition in the electricity sector.

FERC then completely redefined the market with Orders No. 888 and No. 889. The combined effect of these orders was the opening of transmission access to IPPs and the establishment of the Internet-based Open Access Same-Time Information System (OASIS) to organize and manage transmission access (FERC, 2015). This would call for companies to separate the business of operating transmission, and the business of operating generation, in competitive markets, to ensure that all participants have equal access. With this came the need for Independent System Operators (ISO) and Regional Transmission Operators (RTOs). Through Order No. 2000, FERC would promote the development of such third-party operators, cultivating "a full-scale energy and ancillary service market in which buyers and sellers could bid for or offer generation. The ISOs and RTOs used the bid-based markets to determine economic dispatch" (FERC, 2015).

In markets where FERC has determined that its participants “lack or have adequately mitigated horizontal market power, and vertical market power,” the ISO or RTO takes bids from lowest to highest (economic dispatch) to the point of satisfying projected load, setting the clearing price (the price that all generators will receive for their output) at the highest bid required (FERC, 2015). The effect being that generators are incentivized to bid as low as they can, near marginal cost, to successfully sell into the market (Navigant, 2013). This market system inherently encourages efficiency as generators seek to drive down production costs in order to be competitive.

Within competitive wholesale market, two primary markets exist (some of the sub-markets are left out of this review as they fall outside the scope of this thesis), day-ahead markets and real-time markets, or balancing markets. Through the function of day-ahead markets, generators are able to schedule their production for the following day, and load-serving entities (LSEs) are able to inform the market of their projected demand. The real-time market bridges the gap between any disparities in the actual supply and demand in near real-time, to ensure system reliability (FERC, 2015). Once the market clears, ISOs/RTOs calculate the locational marginal price (LMP), at each node within the region (Allcott, 2012). The LMP takes into account the marginal cost of generation, energy losses from transmitting at distance, and congestion. In the event of congestion between two nodes, higher cost generation (that would not be dispatched without congestion present) is dispatched downstream from the congestion, setting a higher LMP at the point of consumption. Here the cost of congestion and the consequent dispatch of higher cost generation is reflected in the LMP (FERC, 2015).

In addition to the day-ahead and real-time market, competitive market operators use capacity markets to ensure resource adequacy and system reliability. LSEs are required to pay for the ready and available capacity as governed by resource adequacy requirements to ensure the reliability of electricity to consumers (Navigant, 2013). Generators (and demand response (DR) providers) bid into the market up to the point of sufficiently satisfying capacity requirements, at which point the clearing price is set. If generators fail to meet their capacity commitments when called upon, they are penalized.

Reserve capacity, presently deemed essential to system reliability, is expensive, the cost of which is ultimately bared by the consumer. In a market where consumers are not exposed to market conditions, the rising cost of electricity in high demand periods fails to be conveyed to the consumer, and thus has no bearing on consumption decisions. In turn resulting in the need for reserve capacity to be called upon. This represents an inefficiency in the market and is part of what provokes questioning the absence of consumer elasticity.

2.2. Efficient Wholesale Pricing

As alluded to above, how prices are determined is at the core of how markets operate, as price signals determine how participants respond to markets (at least in wholesale markets). According to Hogan (2014), markets that implement principles of security-constrained economic dispatch to as full of an extent as possible, are best positioned to achieve efficient pricing and thus evoke appropriate behavior from market participants. Cost causation is fundamentally important to determining price, and essential to this practice is that cost causation follow marginal costs, rather than averaged costs. The allocation of cost must follow these principles as closely as possible, and in real-time, to best promote efficiency in the market (Hogan, 2008). It is through this approach that the guiding principle of competition yields efficient market outcomes. “Standard economic theory suggests that competition and the striving for profit result in (more) efficient market outcomes to the benefit of consumers and the economy, in the form of lower prices and costs" (Pepermans & Proost 2016). The wholesale markets run by RTOs/ISOs, while not perfect, have done much to achieve this model, and thus represent the best opportunities for similar pricing structures at the retail level.

2.3. Linking Costs and Value Between the Wholesale and Retail Markets

What becomes obvious, even in this cursory review of competitive wholesale markets, is that market forces produce volatile, location and time-based prices that do a fairly good job of reflecting marginal costs on the grid. It is important to note that "fairly good" acknowledges diversions away from perfectly functioning markets. As made evident by Hogan (2014), a small fraction of necessary energy and ancillary services fail to be priced into the real-time markets, thus requiring out-of-market solutions such as the aforementioned capacity markets, deemed necessary because the market fails to incentivize adequate resources. While such is the case, the imperfections of competitive wholesale markets are not dealt with at length in this thesis, although dynamic retail rates are believed to offer benefits in reducing the need for out-of-market solutions in the wholesale market. For the purpose of this thesis, I assume that competitive RTO and ISO real-time prices are efficient.

Presently the connection between how cost and value, and ultimately cost causation are transferred from the wholesale market, to retail markets, is largely absent. Consumer behavior is thus blind to accurate cost causation, failing to receive price signals that would otherwise present the opportunity for decision making in respect to price. Exposing the retail market to wholesale market conditions is vital to both general market efficiency, and producing best outcomes for the development of intelligent and flexible distributed energy systems, capable of decarbonization. This disconnect between wholesale and retail market conditions presents a fundamental barrier to consumers having the opportunity to control their energy costs, and ultimately undermines the value of DERs, and distorts resource allocation. It is this separation between wholesale market conditions and retail prices that presents the fundamental issue defined in the "1st Elasticity Issue." When retail rates fail to express market conditions, they negate the opportunity for consumers to behave in accordance to market conditions. To understand how this opportunity is stifled, an examination of the ubiquitous flat rate and its implications is needed.

3. Retail Rates: The Implications of Design

In looking at how retail rates have been designed in electricity markets to date, and how prices are determined in the retail market, one phenomenon is consistent throughout the history of retail electricity markets. That being the averaging of costs across the market, and the failure to account for the variability of costs that truly exist from one time and place, to another. This averaging of costs breeds inefficiency, resulting in myriad market failures as market participants are prevented from making decisions in respect to cost and value because market conditions are masked by flat rates. Energy and Environmental Economics (E3) (2016) views today's rate offerings as lacking "a value-based pricing mechanism that encourages economically efficient behavior and compensates for load response and self-generation in the highest value locations at the highest times." Before further addressing the opportunity for consumers to become active market participants, it is necessary to look at the purpose and function of rate design as a whole.

3.1. Design Principles

Retail rates should achieve two important results. The first being that rates permit cost recovery, both embedded and marginal. That being that utilities are capable of remaining solvent, and will continue to serve customers. The second is that rates influence decision making on both the supply and demand side, for both determining investment, and influencing consumer behavior. The desired outcome is maximized economic efficiency through optimized resource allocation on both sides of the market. For such to be the case, the where and when of costs and value need to be accurately and fairly passed onto customers through distinguishable price signals. Price, when transparent, acts as an agent of information in all markets. It is through the message carried by price that consumers weigh the value of consuming a limited resource and the cost they must bear to consume, ex post facto the owner of limited resources makes decisions in the management of the resource by following the behavior of the consumer, in response to price. This is the essence of economic theory, and it is no less important in the realm of electricity than in respect to any other resource. Yet the history of power markets tells a story where this relationship between resource owner and resource consumer, governed by price, has been greatly distorted. This distortion and the absence of information exchange is the fault of defective retail rate design.

In perhaps the most influential text regarding rate structure, *Principles of Public Utility Rates,* Bonbright, Danielson, and Kamerschen (1988) established the guiding principles for rate design. The principles are best summarized as follows. First, rates should ensure cost recovery, and that each costumer's contribution to utilities cost recovery reflect the costs each consumer imposes (cost causation). Second, rates should promote an efficient market by reflecting marginal costs and promoting competition. Third, rates should be simple and understandable for consumers (Bonbright, Danielson, and Kamerschen, 1988). However, this theoretical ideal, as Bonbright, Danielson, and Kamerschen (1988) note, is troubled by principles running contrary to one another. For instance, ensuring that rates are simple enough for consumers to understand, has historically contradicted promoting economic efficiency through rates that follow marginal costs (sophisticated rate design) (Bonbright, Danielson, and Kamerschen, 1988).[5]

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[5] In addressing the "2nd Elasticity Issue" the conflict between simplicity of rate design and rate design promoting efficiency can be mitigated through technologies that make sophisticated rate design more user friendly.

Given the perceived inability to provide rates that perfectly follow the above principles, utilities have disproportionately emphasized some principles over others. Cost recovery and simplicity have historically been prioritized, undercutting principles that promote efficient markets. Rates that signal the value of DERs, whereby a consumer would source less of their load from the utility, are perceived as representing an existential threat to cost recovery, and even the utility business model (Chitkara et al., 2016). Utility emphasis on cost recovery through averaged costs, represents a significant barrier to dynamic and value based rates, and solving the "1st Elasticity Issue."

In looking at the origin of cost, there are four core services that costs originate from. Customer services, distribution services, transmission services, and generation services. The first three services are regarded as fixed or embedded costs associated with the costs incurred from building and maintaining the grid, and the cost of serving the customer through admin work, metering, etc. (Braithwait, Hansen, O'sheasy, 2007). Conversely, generation services are prone to great variability in marginal costs as market conditions change. However, all of these service costs have typically been passed onto customers through a grossly averaged, volumetric charge per (kWh), meant to reflect the average cost of each kWh supplied to the consumer, and spreading fixed costs over the expected volume of kWhs to be sold (Braithwait, Hansen, O'sheasy, 2007). This rate structure is the basis of the flat-rate tariff that has far and away been the most prevalent tariff in residential retail markets. Flat rates emphasize retroactive cost recovery (historical costs), failing to reflect marginal costs that vary by time and location and would signal the true cost of consumption and the potential value of DERs to consumers. This fundamental break between wholesale and retail markets, and the absence of cost causation, precipitates a series of misallocations, or what can broadly be defined as market failures.

3.2. Market Failures

The concept of market failure is not rigidly defined, and tends to vary from one pundit to the next. This is particularly true because of its relation to government intervention and the divergence between schools of thought and their perception of free markets. Francis M. Bator, in *The Anatomy of Market Failure*, defines market failures in respect to allocation theory, as "the failure of a more or less idealized system of price-market institutions to sustain "desirable" activities or to stop "undesirable" activities" (Bator, 1958). In other words, production and consumption decisions are misinformed.

In a "perfectly competitive market", price is derived from a buyer's willingness to pay at or above marginal cost, and the suppliers willingness to sell at or above marginal costs. From this relationship, the interest of consumers, and suppliers, intersects at a quantity and price that efficiently allocates resources based on the willingness of participants at a given time and place. This maximizes total surplus (Pepermans & Proost, 2016). A market failure takes place when the market is incapable of coordinating what buyers and sellers want because some piece of information regarding the cost and or value of the good is artificially added or subtracted, equating to welfare loss (Bator, 1958).

In translating this idea to retail electricity markets with fixed rates, misallocation is constantly taking place. This market failure (what I'll call the primary market failure) born from information loss in rates that fail to reflect market conditions, both spatial and temporal, equates to over consumption during high price periods and under consumption during low price periods (Braithwait, Hansen, O'sheasy, 2007). But the total effect goes well beyond this initial misallocation. The failure to account for real marginal cost in the past, present, and future, results in misinformed decision making for both suppliers and consumers that equate to "secondary market failures," that result from the primary. One such "secondary market failure" is the masking of DER value, in the absence of cost causation and price signals. In a location where supply shortages and transmission congestion are frequent, DERs could relieve demand, lessening the dispatch of the highest marginal cost generation, and reducing congestion rents, driving down the wholesale price of electricity, for the benefit of all consumers. Upgrades on the supply side, both generation and transmission, could be deferred or outright avoided where DERs offer lower cost solutions (Energy and Environmental Economics, Inc. 2016). Additionally, under flat rates, consumers cross-subsidize one another. When rates fail to follow cost causation principles, higher cost consumers (those consuming when supply is limited and congestion is high) subsidize lower cost consumers (those who consume when supply is ample and congestion is low), as costs are shared equally amongst users, despite users having varying impacts on cost. This undermines efficiency, and prevents consumers from having the opportunity to behave in relation to the costs they impose or don't impose (Gordon and Olson, 2004). Ultimately, supply and demand fundamentals that should produce information to guide decision making, are muted. Absent price signals, DERs and the buildout of robust smart grids are stifled, rendering the energy system incapable of incorporating deep penetration of variable renewables. Such an energy system remains fossil fuel dependent, and a detriment to the climate (EDF, 2015). It is this particular market failure, whereby DER markets, and the build out of smart grids are prevented from developing as they would with transparency of information (price signals that indicate marginal costs), that inspires this thesis to investigate the "elasticity issues."

4. The 1st and 2nd "Elasticity Issues:" Challenges and Solutions

Economists have long been aware of the market inefficiencies born out of flat rates, and have worked to push industry in the direction of more granular pricing mechanisms (Joskow &

Wolfram 2012). However, a number of barriers to market, have historically hampered the development of dynamic rates, and pushed time-variant pricing towards less granular designs. On a technical level, preceding the nuanced challenges surrounding customer utilization, the absence of smart meters has prevented dynamic rate offerings from being viable, thus keeping the "1st Elasticity Issue" from being solved. Conventional electromechanical meters only record kWh, and must be checked manually to record consumption by volume over a time period, rendering time-variant rates (TVRs) useless (Faruqui, Hledik & Palmer 2012). Conversely, smart meters "send real-time consumption data to the utility and make feasible various forms of real-time pricing that tie retail prices to dynamic wholesale prices" (Joskow & Wolfram, 2012).

Not only are smart meters imperative to enabling sophisticated rate design to drive DER growth, but also in the management of the smart grid in acting as the means of data collection and communication to improve grid management, resource use and integration, and resiliency. Ultimately smart meters provide operators with "visibility into the distribution grid that allows them to proactively solve problems" (Cooper, 2016). For these reasons, widespread smart meter roll-outs are taking place across the US and elsewhere in the world, as governments and utilities recognize the role of advanced metering infrastructure (AMI) in the changing energy landscape. In the United States, utilities "installed 65 million smart meters, covering more than 50 percent of U.S. households," by 2015, and 90 million smart meters are projected to be deployed by 2020 (Cooper, 2016).

However, customers using some type of TVR remain a fraction of those with AMI. Faruqui et. al point out that in 2014, when roughly one third of U.S customers were equipped with smart meters, only two percent were on a TVR (Faruqui et al., 2014). This indicates that despite the AMI perquisite barrier being removed, remaining barriers continue to prevent TVR adoption. Two barriers that are particularly relevant to the 1st and 2nd "elasticity issues" are customer concern with price volatility, and the ineffectiveness of TVR rates (Faruqui, Hledik & Palmer, 2012). Rates are made less and less efficient the more they depart from following the volatility of the wholesale price. Yet the closer they follow this volatility, the greater customer concern is in regard to price risk and uncertainty in their ability to manage the volatility (Borenstein, 2005). The history of TVR offerings suggests that accommodating for volatility concerns, has taken precedent over the efficiency of rate design. However, recent developments in technology are changing this relationship. First, I'll provide examples of the types of TVRs most "widely" adopted and tested, and demonstrate their shortcomings.

4.1. Alternative Rates, Pilots, and Programs

In an attempt to better align retail prices with wholesale market conditions, and to expose customers to some variance in the market, a variety of variable rates have been introduced to retail markets, both at the experimental pilot project level, and at full deployment. TVR offerings to date fall under three categories: Time of Use (TOU), Critical-Peak Pricing (CPP), and Real-Time Pricing (RTP). RTP represents the benchmark for "good" rate design. As the name indicates, RTP attempts to follow the real-time wholesale price, thus following marginal costs. As demonstrated below, rates that departure from RTP still result in much of the misallocation observed in flat rates (Hogan, 2014). Before looking at this relationship, it is worth providing a brief overview of each pricing mechanism.

Time-of-use Rates (TOU)

The most basic departure from the flat-rate tariff is the TOU tariff. TOU tariffs reflect approximated and pre-assigned prices for different periods (blocks) of the day based on historical and expected wholesale conditions. In simplistic form this is arranged through peak and off-peak periods, where each period's price reflects the average cost of supply over the period. TOU rates can be further specified to include multiple price periods per day, week, or season (Faruqui, Hledik & Palmer, 2012).

While TOU rates do incentivize consumers to avoid peak period consumption and should equate to load shedding, particularly for those with Demand Side Resources (DSR) (the capacity to manage one's demand), TOU rates fail to reflect short term variations in wholesale conditions. As William Hogan points out, TOU prices are set "well in advance" and therefor are incapable of reflecting value at specific times and locations, yielding inefficient outcomes (Hogan, 2014).

Critical Peak Pricing (CPP)

CPP is a form of time-variant pricing where excess rates are applied to a very limited number of peak hours over the course of the year. During these hours, capacity reserve costs need to be recovered, and therefor demand a super-premium price, sometimes as much as a factor of 10 above average retail prices (Faruqui, Hledik & Palmer, 2012). Typically, CPP excess rates are only levied on some 5% of days per year, and customers are warned of the CPP a day in advance. One form of CPP leaves the CPP period flexible, enabling the system operator to better respond to critical grid conditions. Another form of CPP implements variability into the price over the CPP periods. This type of rate has proven to be effective in stimulating consumer demand response, providing significant load relief, given how strong the price signal is with the super-premium rate, in contrast to the off-peak price (Faruqui, Hledik & Palmer, 2012).

Ultimately these forms of time-variant pricing are not dynamic, thus information loss remains, and customer response is out of sync with actual market conditions. When thinking about the long-term goal of better integrating variable renewables, this is particularly problematic (Faruqui, Hledik & Palmer, 2012). Ultimately rates need to be dynamic and value based in order to root out the market failures described above. RTP captures the dynamic portion of this need, but for reasons that will be addressed in the "2nd Elasticity Issue," RTP is nearly nonexistent in residential retail markets.

Real-time Pricing (RTP)

RTP is presently the "best" attempt at providing a rate that follows cost causation principles, and moves closer to enabling a flexible and intelligent energy system. Depending on design, RTP provides an hour-by-hour price signal to the consumer, tracking grid conditions as they take place, allowing consumers to make informed decisions about their consumption. Any departure away from RTP will impart loss of efficiency in the price, as RTP best reflects the "marginal value of power at a location" (Hogan, 2014). The RTP needs to follow the wholesale market as closely as possible to maximize efficiency. As stated in the TOU section above, setting prices in advance will naturally make this near impossible, given that price fluctuations do not follow a perfectly consistent pattern from day-to-day. This remains true for setting RTP prices. Severin Borenstein's "Time-Varying Retail Electricity Prices: Theory and Practice," refers to this as the "timeliness of prices: the time lag between when a price is set and when it is actually effective" (Borenstein, 2005). A TVR that is "granular," such as a price that changes hourly (RTP), doesn't necessarily follow the wholesale price accurately, when set in advance. Inevitably, predetermined prices will stray from actual prices, and will express market conditions inaccurately. RTP prices can be set a day ahead, or in the hour leading up to each hour. The closer the price is set to its delivery, the more efficient the market (Borenstein, 2005).

To better understand why RTPs, set near real-time, are necessary to drive efficiency in the market, I'll illustrate the economic inefficiencies born from flat rates and the inefficiencies that remain with a TOU. The most obvious market inefficiency is observed through social welfare loss, or deadweight loss caused by a misallocation of electricity where the marginal cost is no longer equal to the marginal benefit. Flat rates deviate from the actual price and quantity that would otherwise be set by supply and demand equilibriums, as illustrated in Figure 3. This misallocation triggers the "secondary market failures" treated in the previous section.

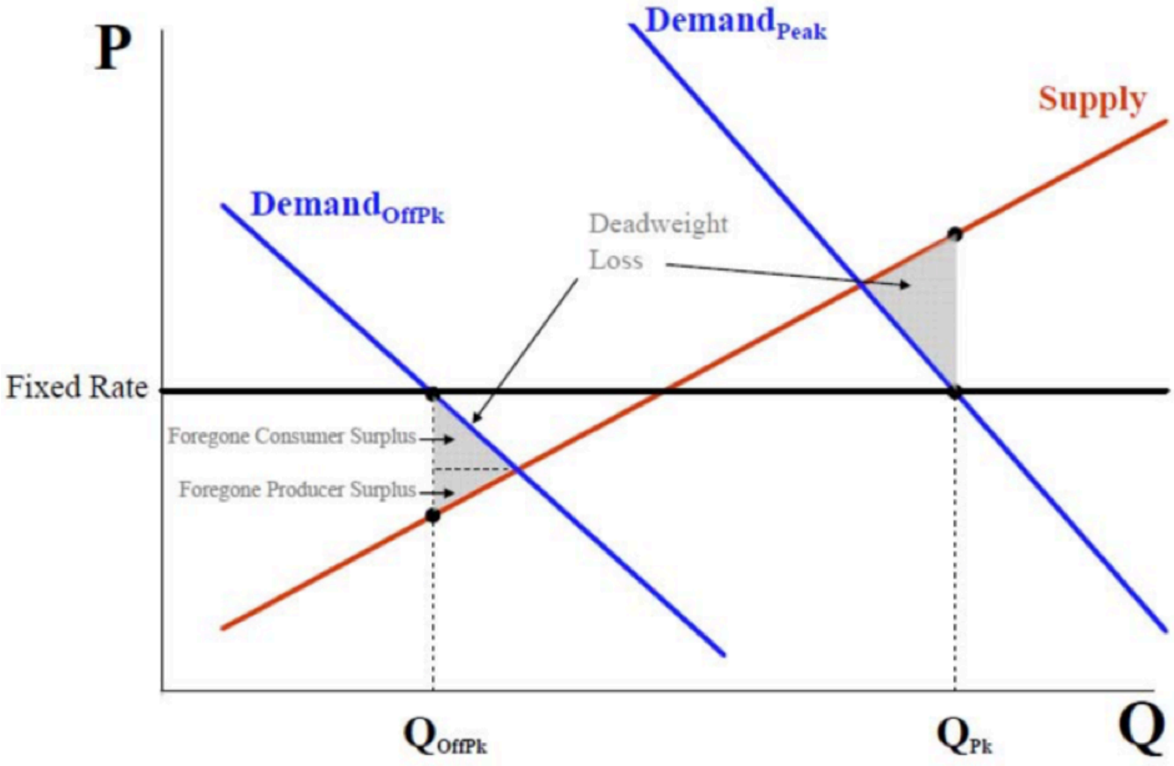

Figure 3: Economic Inefficiencies Caused by Fixed Rates (Faruqui & Newell, 2009)

In relation to Figure 3, Hogan (2014) sets up an example to better understand how much of the deadweight loss created by a fixed rate, remains under TOU rates, even if the TOU rate is extremely accurate in forecasting hourly average prices. To do so, Hogan first provides a month of real-time price volatility data for a PJM (ISO) LMP in New Jersey, and expresses the average hourly price over the course of the month on the black dotted line, shown in Figure 4.

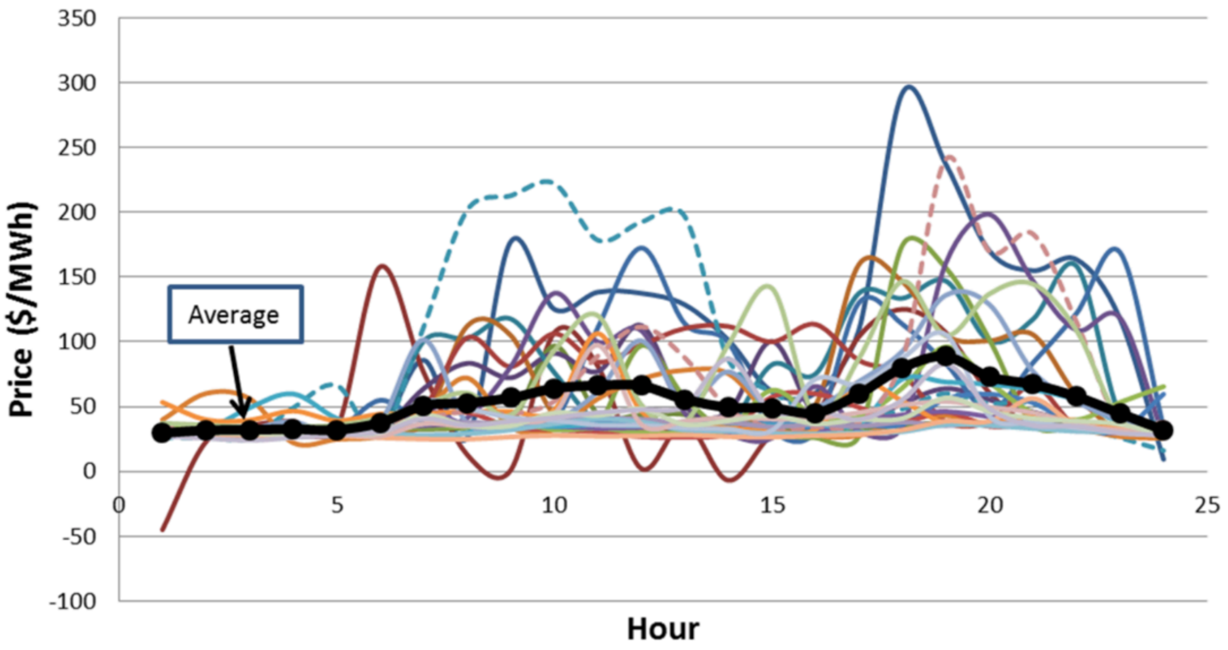

Figure 4: Newark Bay Real-Time LMP, Days in Feb. 2013 (Hogan 2014)

Even if it were possible to perfectly set each hourly price for a month, in advance, (forecasting the black line) the average price will only cover 18% of the variability in actual real-time prices relative to a flat rate, equating to 82% of the deadweight loss incurred under a flat rate, to remain (Hogan, 2014). It's worth emphasizing that the TOU rate used in this example is the best possible forecasted average hourly rate over the month, and still produces more than three fourths of the deadweight loss incurred by the flat rate. Hogan goes on to explain that the variance found in the data sample is not unique, and is in fact replicated all across the PJM region (Hogan, 2014). This is likely the case for LMPs in any competitive wholesale market.

The superiority of RTP over less accurate TVRs, and of course over flat rates, is clear. More accurate pricing maximizes rate designs ability to mitigate market failures. As consumer demand is synchronized with the wholesale market, both generation and transmission capacity investments can be deferred or even outright avoided, downward pressure is put on wholesale prices as the demand curve flattens, DERs are incentivized which further reduces the need for capacity investment, putting further downward pressure on wholesale prices, and variable renewables utilization is improved (increasingly important as renewable penetration increases) (EDF, 2015). However, the total benefit of this kind of pricing is not of concern to the individual customer. The costumer's interest is specific to their own bill and their desire to consume electricity based on convenience. For this reason, the notion of RTP is perceived as representing increased risk because of its inherent volatility and uncertainty over a customer's ability to effectively utilize the rate without changing their behavior. The general consensus being that without sophisticated automation technology governing the majority of a customer's load, RTP is simply too difficult to manage (Faruqui, Hledik & Palmer, 2012). However, it's worth pointing out that large scale commercial and industrial (C&I) consumers have long been using some form of TVR, often times RTP (Faruqui, Hledik & Palmer 2012).

C&I consumers intently monitor their bottom line, and as large energy consumers with high energy costs, an opportunity to improve their bottom line is a priority. Even if it means active management is required. For this reason, among others (necessity of AMI), C&I consumers offered the easiest point of entry for TVRs. Now that AMI is widespread, and technologies that enable price responsiveness are more available and economic, pilot projects testing the viability of different TVRs at the residential level are taking place all over the world (Faruqui, Hledik & Palmer, 2012). However, given that AMI rollouts are a recent development, and the perceived benefit of only gradually exposing residential consumers to more sophisticated rates, the vast majority of TVR pilots and programs at the residential level, have been in the form of TOU and CPP.

While this thesis follows the argument in favor of RTP over todays alternatives, the experience of TOU and CPP programs add valuable insight to answering questions surrounding the “2^{nd} Elasticity Issue,” and the need for enhancing residential consumer’s ability to be price responsive. In looking at the outcomes of a number of TVR pilots and programs, the distinction between customers equipped with some form of response enhancement technology, and those without, in terms of capturing value, and reducing peak load, is extremely prevalent. Enabling technologies include both technologies that convey price information, and technologies that respond to price signals themselves. Examples of technologies that convey information are in-home displays (IHD) (conveying information such as price and consumption levels/patterns) and energy orbs that change color (indicating price periods) (EDF, 2015). Technologies that respond directly to changes in price (automation technology), such as smart thermostats and smart appliances, are capable of receiving price signals and responding “algorithmically to prices and to its estimated probability distribution of future prices,” according to preset parameters (Schneider & Sunstein, 2017).

Faruqui, Hledik, & Palmer (2012), in their survey of 24 residential pilot projects, covering “109 combinations of time-varying rates and enabling technologies” consistently found that TVRs coupled with IHDs and energy orbs, outperformed rates on their own, and that rates with automation technology, served as a significant boost to price response. Figure 5. represents their findings in making this comparison for the 24 projects covered in their study. As indicated by the graph, the peak to off-peak price ratio is strongly correlated to peak reduction, for both consumers with technologies and without, but on average, price response is significantly greater for customers with technologies.

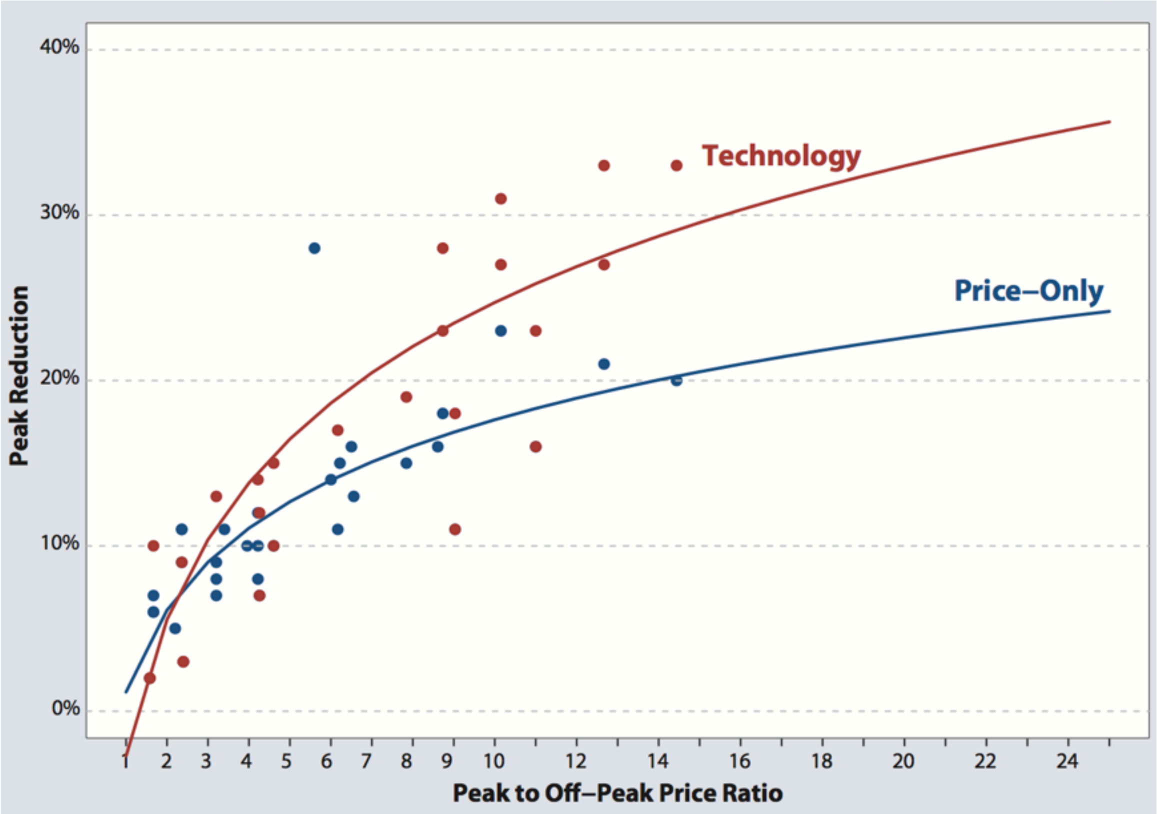

Figure 5: Pilot Impact versus Price Ratio (with and without Enabling Technology (Faruqui, Hledik & Palmer, 2012)

In looking at specific examples that affirm the assumption that enabling technologies equate to quantifiable improvements in response, one pilot in particular, clearly demonstrates this phenomenon. Oklahoma Gas and Electric's "2011 Smart Study Together Pilot" reviewed a combination of TOU and CPP rates without enabling technology, with IHD, and with smart thermostats. The pilot found that response to critical peaks increased by an average of 6% for customers with IHD, and by 17% for customers equipped with smart thermostats (EDF, 2015).

Bollinger and Hartman (2017), in their research on the benefits of enabling technologies, make a similar distinction between the impact of information technologies and automation technologies. In studying a field experiment "conducted by a large southern utility" (US), covering 2,210 households, Bollinger and Hartman's analysis found "significant demand reductions for the portal and IHD, but the demand response to price is one-fifth of that for those with automation" (Bollinger &Hartman, 2017), again, reinforcing the argument that automation technologies yield superior price response. Another recent study, with 5,531 households located in one of the three major utilities in the California Independent System Operator (CAISO), looked at the effects of consumer inattention and automation in respect to dynamic pricing. The study found that consumers with automation technology (when responding to pricing events) reduced load by more than 56% in comparison to consumers without automation technology (Gillan, 2017).

The general conclusion drawn is that both awareness of price, and automation technology, are significant factors in improving consumer response ability, with the latter having the greatest impact. As these types of technologies improve in their ability to receive actionable information, and to make sound energy consumption decisions in accordance with the customers preset parameters, customers are made more capable of price response, with little behavioral change. Thus the "2nd Elasticity Issue" becomes less and less of a barrier to implementing the kind of dynamic rates needed to spur smart grid adoption. In preceding with the remainder of this thesis, I'll assume that the "2nd Elasticity Issue" is solvable, and as technologies continue to improve in their ability to act autonomously and to control micro-loads within a household, customers will become increasingly capable of responding to price signals. Before addressing the "3rd Elasticity Issue" one additional component of the "1st Elasticity Issue" requires further treatment.

To adequately resolve the "1st Elasticity Issue" it's important that the "opportunity" to be price responsive is the right opportunity. By that I mean that the price signal that is intended to evoke a price response, accurately reflects market conditions. RTP takes a significant step towards accurately corresponding with marginal costs in the present. However, as further explained in the subsequent section, RTP fails to account for future marginal costs, or rather marginal costs that are "avoidable," (i.e. utilities can avoid transmission capacity upgrades because DERs have reduced the need for transmission capacity) if the locational value of DERs is accounted for in rate design (Energy and Environmental Economics, Inc. 2016). Thus, a integral rate component in terms of stimulating the smart grid, is absent. It is this treatment of locational value and accounting for "avoidable costs," that E3's Full Value Tariff uniquely addresses. As E3 states, "area differentiation is critical to induce investments that can support load management or generation in the high value (constrained) areas at the appropriate times in order to maximize the value of DERs to the grid" (Energy and Environmental Economics, Inc., 2016). Adding this value on top of RTP is what makes E3's FVT deeply impactful in moving towards creating the "right opportunities" to be price responsive.

5. E3's Full Value Tariff

E3's report, "Full Value Tariff Design and Retail Rate Choices" provides a tariff that sets dynamic marginal prices equal to marginal costs that vary by time and location. By doing so, FVT customers receive prices that reflect the costs they do, or do not impose (cost causation) on the network, and its assets. By Following Bonbright et al. (1988) cornerstone principle of cost causation (the bedrock of efficient electricity markets), each customer's costs can be competed against by DER solutions, where DER value exceeds those costs (Energy and Environmental Economics, Inc. 2016). The principle of cost causation is present across each of the three components that make up the FVT, with each component carrying a charge that represents a different aspect of the cost of providing electricity.

The first component, the "customer charge," is a fixed $/customer charge, that seeks to recover the embedded costs that all customers impose, independent of costs related to consumption. These are primarily fixed administrative costs such as metering and billing that all customers impose equally and thus should be recovered equally. The second component is a size based "network subscription charge" that equitably accounts for the extent to which a customer depends on the grid, and thus accounts for the share of embedded costs each customer is "responsible" for. This component is levied in the form of a $/kW-month charge, with kW per month ideally accounting for a customer's coincident and non-coincident peak demand,[6] representing the extent of a customer's system use (costs they impose). The third component, the "dynamic price," is the FVT's most significant and unique contribution to innovative rate design. The "dynamic price" takes real-time pricing and adds forward looking accounting of "distribution value" on top of the RTP. The "distribution value" is derived from forward looking marginal costs of projected sub-transmission and distribution upgrades to meet future demand. The forward looking marginal costs indicate the value of mitigated demand in avoiding future sub-zonal transmission and distribution investment for a particular location. I.e. "avoidable costs." The "dynamic price" component sets both present and future marginal costs equal to the hourly marginal price, and is charged on a volumetric basis, $/kWh (Energy and Environmental Economics, Inc., 2016). Once again, closely following cost causation principles.

In combination, the three rate components pass on the true underlying costs of serving each customer's specific load, and allow for equitable recovery of embedded costs based on each customer's consumption. By exposing customers to the true costs they impose in respect to the

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[6] Coincident peak demand is the customer peak demand taking place at the same time as system peak demand, while non-coincident peak demand is customer peak demand that may take place outside of the systems peak demand period (Energy and Environmental Economics, Inc., 2016).

time and location of their consumption, the costs represent potential value in terms of being avoidable. In other words, an opportunity for customers to mitigate costs through demand-side resources is created. DERs are put in a position to compete against a customer's marginal costs, and when deployed in light of superior cost performance, provide value to the grid. E3 refers to this as accounting for "full value." In their words, "the sum of time-variant and area-specific avoidable cost components of DERs and load changes that are on the margin and currently monetized in electric retail rates." (Energy and Environmental Economics, Inc., 2016). At its very essence, the FVT prompts customer engagement in managing their costs through DER driven load response and net injections. With this overview, the FVT concept is made clear, but what deserves additional attention is how costs and value are accounted for and allocated in each component's charge.

5.1. Accounting for Cost and Value

The **"customer charge"** component of the FVT is straight forward. All customers impose the same costs in relation to their being serviced by the utility in regard to metering and billing, and thus all customers should pay the same flat rate for this service. This portion of the bill is calculated by evaluating a utility's "embedded cost of service studies" (or an equivalent) that utilities are required to produce for state public service departments, to gage the utility's required revenues (Energy and Environmental Economics, Inc., 2016). The "customer charge" provides no signal of value (with the exception of disconnecting from the grid all together), but acts as a necessary means of cost recovery in accordance with cost causation.

For the **"network subscription charge"** component, the extent to which each customer depends on the grid's infrastructure (transmission, sub transmission and distribution) can vary considerably from one customer to the next, thus each customer's contribution to recovering those embedded costs, should be commensurate with the costs they impose. This is analogous to cell phone carriers requiring that customers subscribe to a monthly allotted quantity of data (Energy and Environmental Economics, Inc., 2016).

E3 presents a number of approaches to calculating the "network subscription charge," all with varying degrees of economic efficiency. As is often the case, the most economically efficient designs are the most complex and hardest to understand from the customer perspective. With this in mind E3 concludes that a customer's "rolling maximum monthly energy charge" over a 12-month period, be used to assign a $/kW-month subscription charge that reflects the customers cost to the grid in that billing year. While this portion of the tariff doesn't account for "use coincident with the system and the sub-transmission and distribution level peaks," i.e. a customer's most costly load, this aspect of cost causation is dealt with in the "dynamic price" component (Energy and Environmental Economics, Inc., 2016). Ultimately "the network subscription charge" results in fair allocation of the grids embedded costs, and indicates a degree of value in reducing grid use through DERs that reduce total energy consumption from the grid (Energy and Environmental Economics, Inc., 2016).

The FVT's greatest indicator/determinant of DER value is the price signal derived from the **"dynamic price"** component, and its expression of marginal "avoidable costs" (Energy and Environmental Economics, Inc., 2016). The dynamic real-time price contains the marginal "avoidable cost" of the LMP (including line losses), and ICAP[7] values. This portion of the "dynamic price" expresses the cost of energy, generation assets, the limitations of transmission capacity, and their corresponding price in respect to market conditions, sending a price signal

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[7] ICAP- For New York Independent System Operator (NYISO), load serving entities are required to procure enough installed capacity (ICAP) to meet the ISO's capacity requirements in accordance with reliability standards. (NYISO, 2017) The other deregulated US markets have similar capacity mechanism/markets that can be built into the dynamic price in the same way the ICAP value is here applied.

that indicates the value of DERs, in respect to time and location. The "distribution value" component of the "dynamic price" accounts for the "avoidable costs" for the sub-transmission and distribution systems, and sends a price signal that corresponds with local grid constraints.

In order to incorporate the "distribution value" into the dynamic price, E3 suggests "constructing a forward looking marginal cost ($/kW-year) for each area, linked to a utilities capital budget for the next increment of capacity by area" (Energy and Environmental Economics, Inc., 2016). In effect, making these calculations determines the costs that DERs will compete against, if DERs can meet the same objectives in ensuring adequate distribution to meet an areas load. E3 proposes that this be done by calculating the distribution utility's expected capital expenditures (CAPEX) through utility reporting requirements such as Distribution System Implementation Plans (DSIP)[8], or other similar reports on system upgrades to meet future demand, and their proposed "least cost projects." By determining which CAPEX items "are driven by forecasted load growth and needed load relief," this can be used to "determine the marginal value of load relief that would avoid or defer the capital cost" (Energy and Environmental Economics, Inc., 2016). In deferring or outright avoiding CAPEX, the utilities present value of required return (PVRR) decreases in relation to the period of time the CAPEX is deferred. The avoided cost of deferral is derived from mitigated capital costs and the interest rate prevailing at the time a project would be financed. Given that sub-transmission and distribution upgrades are large CAPEX items, deferral equates to significant costs savings to be remunerated to consumers and prosumers, responsible for alleviating points of congestion. By calculating deferred CAPEX for an area on an annual basis, and applying these "avoidable distribution costs" to the forward looking marginal costs, "full value prices" can be created

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[8] DSIP- In the state of New York, utilities are required to report projected distribution upgrades for areas that are expected to face congestion issues. (NYISO, 2017)

(Energy and Environmental Economics, Inc., 2016). However, to do so the "distribution value" must be soundly allocated.

E3 proposes allocating the annual "distribution value" through the top 100 peak demand hours (trigger points/ tipping points for CAPEX), where each hour has a proportional impact, and receives a proportional percentage of the "distribution value." As shown in Figure 6, value determined by the change in the utility's PVRR, is assigned to these hours above the threshold, and passed on as costs that incentivize DER and load reduction solutions to provide the value. In other words, consumers/prosumers offering the load reduction or producing in these peak hours, will benefit from the high price periods, while enjoying lower overall prices because the utility's revenue requirement has been lowered.

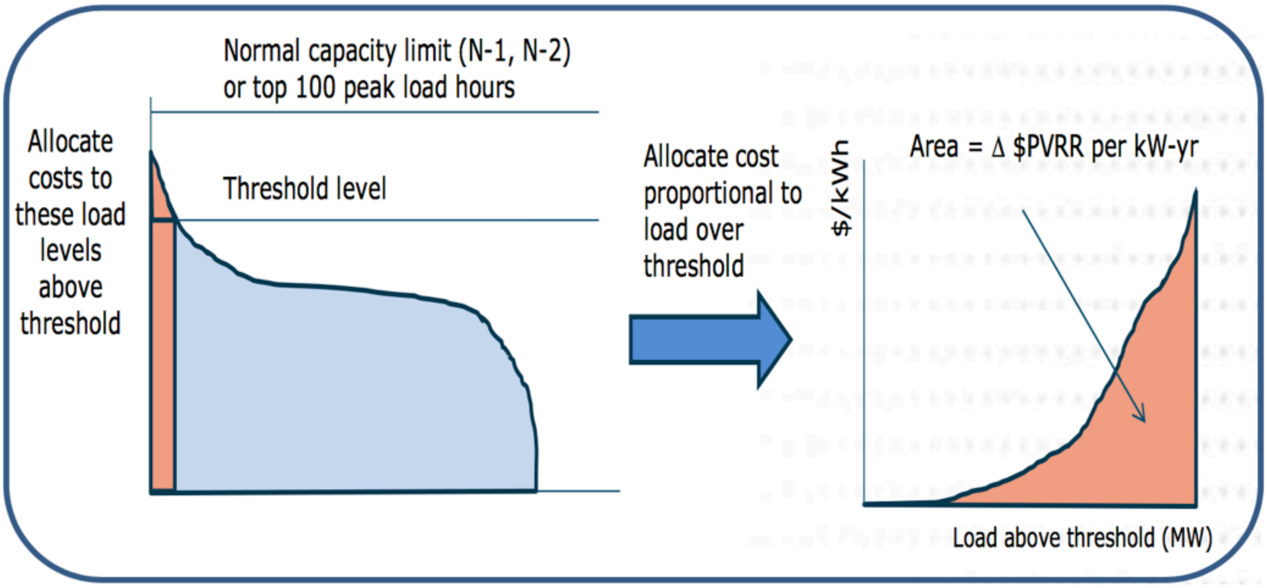

Figure 6: Illustration of E3's "distribution value" allocation rule (Energy and Environmental Economics, Inc., 2016)

Finally, the "distribution value" needs to be incorporated into the "dynamic price." The "dynamic price" would primarily consist of the LMP, energy losses, and ICAP values, but with "distribution value" built into the top 100 peak hours of the year. In these hours above the threshold, the premium price encourages load reduction and net injections (net injections receiving the premium price) (Energy and Environmental Economics, Inc., 2016).

To counter the higher “distribution dynamic price” and to ensure average customers who remain nonresponsive to prices, wont experience bill increases, customers on the FVT will receive bill credits. The bill credits should be equal to expected revenue from the higher price, however given the opportunity for customers to take advantage of the “distribution dynamic price” through DER management, the revenue should be less than the bill credit (Energy and Environmental Economics, Inc., 2016). If the tariff works as intended, projected grid upgrades are deferred or deemed unnecessary, and all rate payers benefit from lower utility revenue requirements.

E3 acknowledges the many hurtles to this type of rate design being adopted at scale, and delivering on its objectives. They primarily sight, the pace at which DER technology advances, smart meter presence, customer acceptance, and the role of “new business model formation around the ‘full value’ dynamic rates” as being the greatest determining factors. This thesis contends that in light of the “3rd Elasticity Issue,” both 3rd party business participation, and favorable policy will be inextricably necessary for this type of rate to succeed.

6. Willingness and Apathy: The “3rd Elasticity Issue”

For this section I assume, that the opportunity and ability barriers are alleviated by the availability of good rate design (something akin to FVT) and technologies that allow for value capture and cost management, with limited need for user input. Ergo, the incentives out way the aversion to risk and complexity. The economics stack up, and changes in the consumption of electricity in response to price signals does **not** equate to the need for consumers to dramatically change their behavior (lifestyle and preferences related to energy use remain largely unchanged because of smart appliances, HVAC, EV charging, etc.).

Under these conditions, a rational consumer who acts in his/her economic interest is incentivized to adopt a dynamic and value based rate, and to procure DER solutions and enabling technologies that capture value. If consumers were “homo economicus,” or as Richard H. Thaler and Cass R. Sunstein (two of the world’s leading behavioral economists, and coauthors of the best seller, *Nudge: Improving Decisions About Health, Wealth, and Happiness* (2009)), refer to the economic man as “econs,” it’s fair to assume that consumers would take this action. With that, residential retail electricity markets would experience significant shifts towards sophisticated rate design, with DER and smart technology growth following suit, assuming the “1st Elasticity Issue” has been alleviated. However, as Thaler and Sunstein argue, consumers are not “econs,” but rather very imperfect economic thinkers and decision makers (Thaler & Sunstein, 2009). Even in making relatively simple decisions that require minimal effort, time and time again, humans fail to act in their own self-interest and ultimately are not as incentive driven as we once believed them to be. Even when the stakes are high, humans are prone to making less than optimal decisions, or simply not making decisions at all.

The burgeoning field of behavioral economics looks at economics through the lenses of cognitive science and psychology. Thus, assessing the impact of cognitive biases on market outcomes that have historically been modeled under the assumption of the economic man (Thaler & Sunstein, 2009). Research suggests that cognitive biases result in pervasive uneconomic human tendencies that are deeply impactful in determining market outcomes. One bias of particular interest in respect to the adoption of sophisticated rates and DERs, is what is referred to as the “status quo bias.” The “status quo bias” suggests that “people have a strong tendency to go along with the status quo or default option" (Thaler & Sunstein, 2009); that the present state has such great inertia that we are naturally inclined to acquiesce, because it's simply easier to go with the flow, than to exert time and effort to make decisions that may be better aligned with our interests. Thaler and Sunstein's, *Nudge: Improving Decisions about Health, Wealth, and Happiness* (2009), demonstrate that this holds true even when the stakes are high.

The primary example cited pertains to how 401(k) (Tax-free retirement savings plans) participants make decisions, or rather don't make decisions in how they allocate income to their 401(k) plans over the course of their careers. The authors make note of a study that found that more than half of college professors fail to make any changes in their asset allocation to their tax-free retirement savings, over the course of their careers (Samuelson & Zeckhauser, 1988). This is stunning for two reasons. One, the benefit of using a tax shelter like a 401(k) has extraordinary implications (long term capital gains tax is typically between 15% and 20%, depending on tax brackets, while 401(k) accounts are nontaxable). Second, college professors are likely closer to behaving like "econs" than your average joe, and yet half of them make this nonsensical error in a high stakes, easy win scenario. But why? It seems that people's acceptance of inertia and the status quo is largely due to apathy, or what Thaler and Sunstein call the "yeah, whatever" heuristic (Thaler & Sunstein, 2009). The inconvenience of taking action to improve a situation or outcome, seems to outweigh considering the benefit. When any complexity arises, we capitulate to the default because we assume its sufficient. Famed economist, Herbert Simon called this aversion to complexity, "bounded rationality." In essence, bounded rationality states that consumers make decisions with "cognitive limits," and that those limitations result in our making decisions we deem to be "good enough." Simon calls this "satisficing," sufficient and satisfactory, but ultimately not economically optimal (Simon, 1979).

In applying these ideas to how residential retail consumers may respond to the availability of rates such as the FVT, in a scenario where the economic benefit is clear, DERs can further leverage value accounted for in the tariff, automation technology ensures little to no manual input, and that ultimately customers will feel no impact on how they consume electricity, there is little certainty that consumers will make the switch. What is likely, is that both "status quo bias" and "bounded rationality" will present significant hurdles in getting retail consumers to switch to dynamic and value based rates, and subsequently, to adopt DERs. In order to bring these concepts of behavioral economics closer to the subject, it's worth applying them to a less granular level of the retail electricity market, and one that has largely played out. That being markets that allow customers to choose their retail provider, commonly referred to as "retail choice" markets.

From the mid 1990s to early 2000s, following deregulation in many of the US wholesale markets that had been inspired by high retail electricity prices, some 22 states moved to bring competition to the retail market (Christensen Associates Energy Consulting, LLC., 2016). To do so, states mandated that utilities open supply markets to competitive suppliers. The general idea being that opening up retail markets to competitive suppliers would put downward pressure on retail prices (at least in the short run), improve customer service, and stimulate innovation (such as dynamic pricing, offering clean power and DER alternatives.) Holding all things equal, at its most basic level, competitive suppliers would offer the same electricity service as the default utility, but at a lower price point. In theory this would commoditize electricity, causing suppliers to squeeze one another's margins as they compete for business, in turn promoting innovation and efficiency, and ultimately product differentiation. In the onset of opening markets to retail choice, the reasonable assumption was that a significant percentage of customers (both residential and commercial), would switch to lower cost providers, particularly if switching was made easy. However, studies indicate that this has hardly been the case for residential customers.

Before reviewing the outcomes of what I'll call "same service, better price" retail choice markets (I'm making this distinction as to not include different service/tariff options) retail choice markets, it's worth drawing the connection between how residential customers responded to "same service, better price" and how they will likely respond to the opportunity to manage cost through sophisticated rates and DERs. Generally speaking, both phenomena pertain to optimizing the customer's relationship to their electricity consumption, both representing some degree of opportunity for better economics, i.e. lower costs. But in order to do so, both require attention, effort, and action by the consumer to enroll, and thus benefit. Both (under the assumptions described above) equate to insignificant changes in regard to service and the ability to seamlessly access electricity, yet consumer's cognitive biases make inciting even a nominal level of attention, effort, and action to change service, difficult to come by.

Conceptually, I assume that it's easier to see value in getting the same service but at a lower price, than reducing cost through dynamic and value based rates paired with DERs and automation. Its straight forward, is easy to do, and it makes financial sense, but for residential customers, the odds heavily favor remaining with the default provider. To illustrate this point, I'll now draw from two comprehensive studies on retail choice markets.

In a 2014 review of the retail choice markets, from inception to present, Christensen Associates Energy Consulting looks at outcomes in all of the retail choice states. Their report, "Retail Choice in Electricity: What Have We Learned in 20 Years?" found that "In U.S. jurisdictions with retail choice, roughly half of commercial and industrial load has switched to competitive suppliers, while under a tenth (7%) of residential load has done so" (Christensen Associates Energy Consulting, LLC, 2016). While these figures represent averages across states, some states did in fact have a majority of residential customers switch to new suppliers, but only when aided by some type of mandate. In the case of Texas's retail choice program, all customers moving to new residences are required to choose a retailer. Thus, removing the inertia around the default, because there is no default (Hortacsu, Madanizadeh & Puller, 2017). Figure 7 is representative of switching rates in each state, and clearly demonstrates the disparity between commercial/industrial switching rates (motivated by bottom-line improvement) and switching rates for apathetic residential consumers.

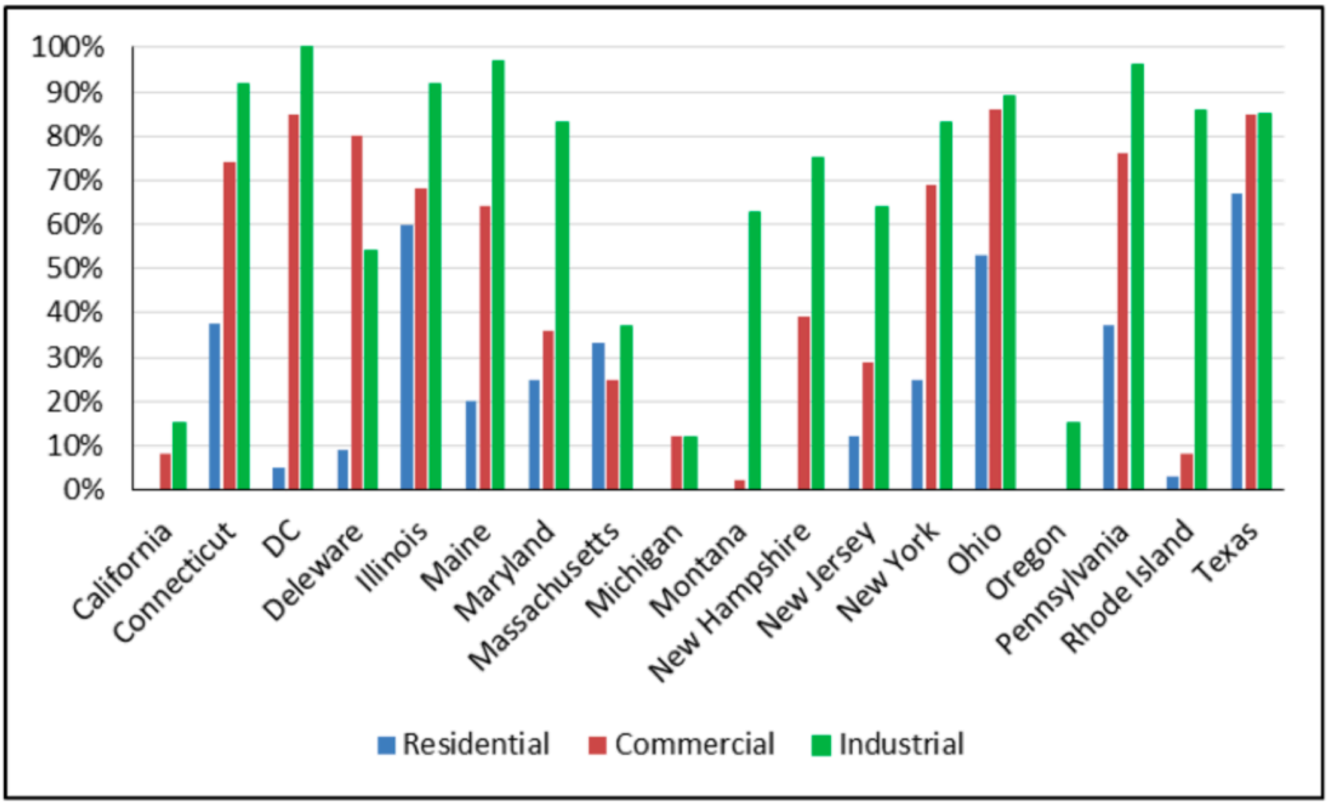

Figure 7: US Competitive Retail Energy Suppliers' Retail Sales as Shares of Total MWh Sales, 2014 (Christensen Associates Energy Consulting, LLC., 2016)

In the case of Texas, even with the mandate, nearly 40% of retail customers fail to switch to a competitive supplier, despite clear opportunities for significant cost savings. In a study specific to Texas's retail choice market, "Power to Choose? An Analysis of Choice Frictions in the Residential Electricity Market," the study found that in the first four years of retail choice, the retail kWh price offered by the default was "consistently higher" than multiple new entrant competitive suppliers (Hortacsu, Madanizadeh & Puller, 2017). Figure 8 shows the comparison between the incumbent price and new entrant retailer prices, reflecting that opportunities for retail customers to reduce their electricity bills, existed the vast majority of the time.

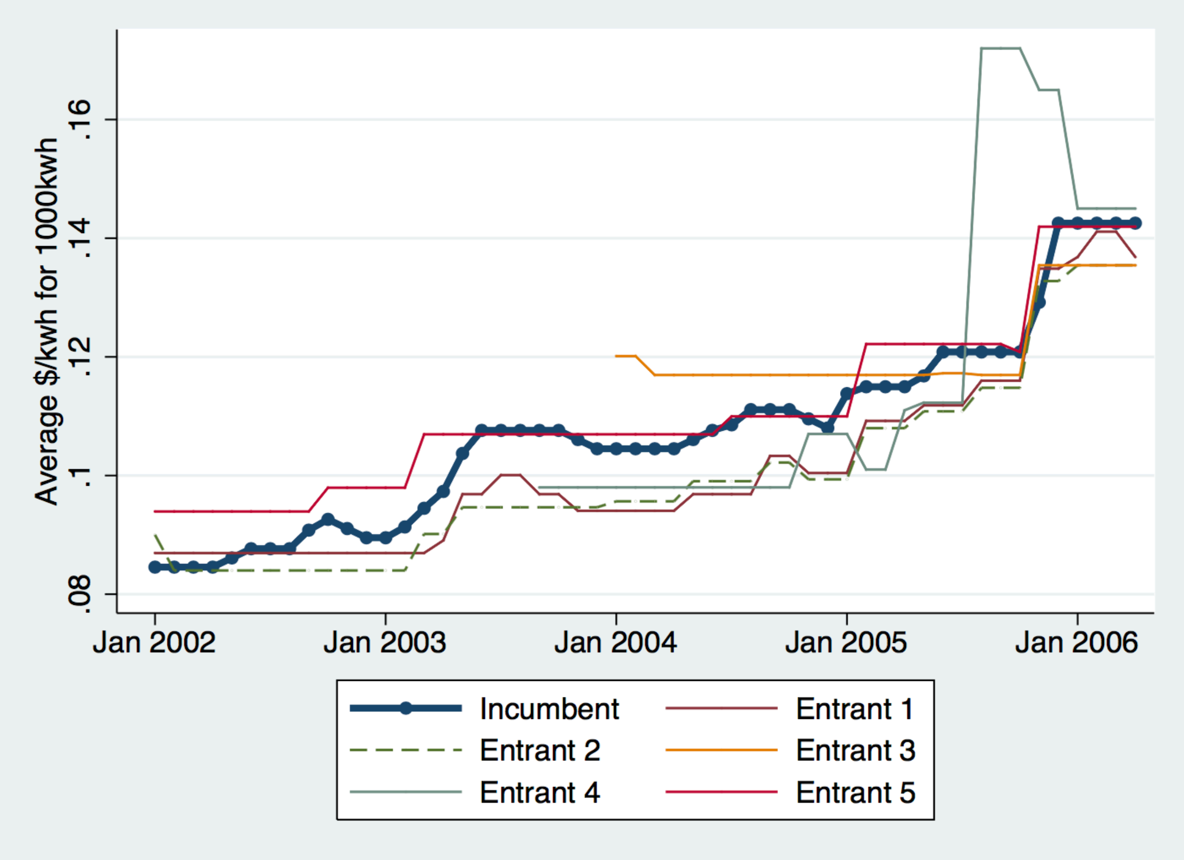

Figure 8: Prices Charged by Incumbent and New Entrant Retailers in First Four Years of Texas Retail Choice Market (Hortacsu, Madanizadeh & Puller, 2017)

Yet despite residential consumers having the opportunity to cut their electricity bills by roughly 8% or $100, requiring a mere 15 minutes to log onto the Public Utility Commission of

Texas's retail choice website, *www.powertochoose.com*, and in a single action, switch providers, consumers fail to do so (Hortacsu, Madanizadeh & Puller, 2017). How is it possible that households would forgo an annual savings of $100 when all that is required is 15 minutes of their time? The report points to two primary factors that the authors refer to as "choice frictions." The first "choice friction" combines two conditions covered in the behavioral economics section above; "inattention/status quo bias." Whereby consumers are either unaware of their ability to switch and its potential savings, or the inertia of the default is greater than their willingness to explore alternatives. The second "choice friction" they identify is what they refer to as "incumbent brand advantage/ product differentiation." This being consumer's tendency to assume that services from alternative suppliers will be inferior to the default (Hortacsu, Madanizadeh & Puller, 2017). Both "choice frictions" are very much applicable to how residential consumers perceive variable rate options.

Much the same, the power of the default has significant weight. For consumers to consider alternative rate designs, they must be willing to overcome what Schneider and Sunstein (2017) refer to as the "effort tax". However, as previously stated, the additional complexities (both in terms of understanding and utilizing the rate) and the general esoteric nature of time-varying rates, beyond "same service better price," imparts a commensurately greater "effort tax." To combat the "choice frictions" for "same service, better price," Hortacsu, Madanizadeh and Puller (2017) suggest "information interventions" (such as information pamphlets attached to utility bills), a low-cost solution for dispelling misconceptions about product differentiation, difficulty of switching providers, and cost savings. However, given the greater "effort tax" for switching to a TVR, this type of soft "nudge," likely won't suffice. In light of consumer resistance to switching rate structures (and increasing appreciation for the benefits of rates that better reflect marginal costs), a hard "nudge" policy solution, switching the default from the flat rate, to some form of time-variant rate, is receiving considerable attention (Schneider & Sunstein, 2017).[9]

A recent study carried out by the Sacramento Municipal Utility District (SMUD), funded by the Smart Grid Investment Grant,[10] tested this very idea. The study, encompassing 174,000 residences, tested the impact of offering a TOU rate as the default, with the ability to "opt-out" (back to the flat rate), compared to offering a TOU rate on an "opt-in" basis, when households were randomly placed into one of the two designs (Cappers et al., 2016). The results showed significant sticking factor in the "opt-out" group, with some 98% of households remaining on the TOU rate, whereas only 19.5% of households in the "opt-in" group made the switch to the TOU rate, despite the potential economic benefits being clear (Cappers et al., 2016). While this provides evidence of the potential benefit from this type of aggressive policy, a number of important questions remain.

6.1. Sophisticated Retail Rates as the Default: Challenges and Opportunities

If consumers are defaulted to some type of time-variant rate, how price responsive are they going to be, what Schneider and Sunstein (2017) refer to as "follow-on consumption behavior." The Cappers et al. (2016) SMUD study concluded that on average, consumers in the "opt-out" group (TOU as the default), reduced their peak consumption by a fifth of those who elected to "opt-in" (flat rate as the default). Getting consumers on time-varying rates, is only

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[9] A nudge, as defined in *Nudge: Improving Decisions About Health, Wealth, And Happiness* (2009), "is any aspect of choice architecture that alters people's behavior in a predictable way without forbidding any options or significantly changing their economic incentives." In the context of switching the default rate, if the consumer is able to "opt-out" this is still a nudge, rather than a paternalistic measure (Thaler & Sunstein, 2009).

[10] In the aftermath of the financial crisis, The American Recovery and Reinvestment Act, allocated $3.4B to smart grid development in an effort to spur economic growth through transitioning the power system towards the smart grid. (DOE, 2012)

beneficial to the extent of consumer's price response. Yet despite "opt-out" consumers being only 20% as price responsive as "opt-in" consumers, the much larger number of customers enrolled in the TVR through the power of the default, results in greater peak reductions. The aggregate of many marginal responses, from a much greater number of customers, equates to total peak reductions far greater than those offered by the elastic "opt-in" customers (Cappers et al., 2016).

Faruqui, Hledik, and Lessem (2014), in a similar study testing the effectiveness of default TVRs, point out that while 57-64 % of customers would not have elected to "opt in" and are thus significantly less price responsive (33% by Faruqui et al. calculations), the exponentially greater enrollment under "opt-out" scenarios, equate to total peak reductions that are 200% greater than "opt-in" scenarios. While these analyses suggest the overwhelming benefits of default TVRs, despite lackluster response from the majority of enrolled customers, these studies do not address "follow-on consumption" for the most granular forms of pricing. When considering the most economic rates (RTP, or better yet FVT), challenges with "follow-on consumption" are likely more pronounced, which may undermine the benefit of implementing more sophisticated rate designs, above TOU or CPP.

While I assume the "2nd Elasticity Issue" is solvable, in that cost-effective automation technologies will be increasingly available, and can dramatically improve the consumer's ability to utilize time-variant rates (particularly real-time rates), consumers will need to seek out these technologies. This in itself represents an additional "effort tax," and to a degree, defeats the purpose of using the default approach to counter consumer biases. Given the strong correlation between enabling and automation technologies, and successful response, particularly when augmented by DER assets (smart appliances, smart charging of EVs, storage, etc.), this represents a significant challenge in getting consumers to be price responsive, and to take advantage of DERs where value is present. Schneider and Sunstein (2017), in regard to implementing time-variant rates as the default, recommend specifically targeting those with smart assets for RTP as the default, while setting the default to either TOU or CPP, with price signals being sent via text, for the majority of residential consumers. However, as previously addressed, TOU and CPP, while better than flat-rates, still deviate significantly from actual marginal costs (Hogan, 2014). In agreement with Hogan (2014), given the challenges in implementing new price structures, particularly in light of consumer's cognitive biases, "it is best to follow first principles and use the best prices we have available. We may not get another chance soon" (Hogan, 2014).

In attempting to address the issue of placing ill-equipped consumers on too granular of a default rate, I see the intersection of the private sector and public sector as being critical. If a rate akin to the FVT were to become the default, a rate that truly accounts for cost and value in both time and location, and the value is great enough, third party DER/ESCO businesses will be motivated to enter the market to sell households varying tiers of what I'll call "flexibility packages," based on the potential value of DERs and automation technologies, for a given location, signaled by the FVT. This could range from a single technology approach as simple as smart thermostats that enable a degree of load shifting, to complex packages pairing automation technology with on-site generation and storage. Where the FVT signals "enough" value, businesses will be motived to help consumers capture value, in turn taking a portion of the cost savings in exchange for their service.

Given that much of the success of FVT as the default option, is predicated on the expectation that the policy measure will induce a private sector response that in turn makes the policy measure effective, caution is warranted. Naturally this will generate concern over the effectiveness and swiftness of the private sector mobilizing to outfit consumers that experience significant bill impacts. However, critical to understanding this expectation, is that consumers who experience the most significant negative bill impacts under the FVT, will likely represent the best candidates for "flexibility packages," and thus the best opportunities for third parties to extract a portion of value. To a degree, the problem is the solution. However, it's worth noting that this may not hold true for households with the smallest loads because potential cost savings, on a dollar basis are not worth third-party intervention. However, the charge structure of the FVT inherently protects smaller energy users. By cutting the tariffs energy charge component roughly in half (in comparison to flat-rates), and reallocating much of this charge to the size based "network subscription charge" component of the FVT (consumers maximum dependence on the grid), bill impacts on inelastic small users, are likely insignificant. (Energy and Environmental Economics, Inc., 2016).

Nonetheless, thoughtful coordination and timing between policy makers, system operators, and the private sector, well in advance of rolling out a new default rate, would be an absolute necessity. A number of important questions will require thorough investigation to ensure the viability of this approach. Priority questions: Testing the viability of the third party "flexibility package" provider business model, consideration of public-private partnerships, potential subsidies, data sharing, utility incentives, consumer protections, consumer education programs, and many more in addition to the many technical side questions particular to coordinating grids with deep DER penetration. Undoubtedly, much uncertainty needs to be addressed in considering this solution. What I can be certain of, is that the smart grid and widespread adoption of DERs, in the name of decarbonizing the power sector, requires the ubiquity of rates like the FVT. In light of consumer biases, households left to their own devices aren't going to stimulate the demand-side on their own. They require a strong "nudge" in the direction of their own self-interest. A final certainty: where extractable value exists, the private sector will go to work.

7. Conclusion

This thesis contributes to the dialogue surrounding the greatest challenges posed by stimulating demand-side participation from residential retail consumers, in an effort to drive DER growth and smart grid adoption. Stimulating demand-side participation requires that consumers be responsive to wholesale prices that vary by time and location. I find that three "elasticity issues" stand in the way of consumers participating in energy markets in a way that yields an efficient market, and an intelligent, flexible, and DER rich energy system capable of decarbonizing. The "1st Elasticity Issue" pertains to consumers having the opportunity to be price responsive, and to receive price signals that reflect true marginal costs, and the value of DERs in respect to market conditions. To remedy this, I suggest E3's "Full Value Tariff." The "2nd Elasticity Issue" addresses consumer's capability to be price responsive when exposed to real-time prices. Research suggests that when consumers face granular pricing, they require automation technology and "flexible assets" in order to be successfully price responsive. However, both electing to be placed on a rate such as the FVT, and acquiring technologies that enhance a consumer's ability to extract value from this type of tariff, requires that consumers be motivated to overcome the "effort tax" of doing so. The "3rd Elasticity Issue" addresses consumer's cognitive biases that result in apathy and unwillingness to take action, despite clear economic benefit. In light of consumers lacking motivation, I suggest that consumers need to be placed on a rate akin to the FVT as the default retail rate, and that third-party DER/ESCO businesses will need to enter the market of providing consumers with “flexibility packages,” in order for consumers to utilize this type of rate. The low carbon smart grid of tomorrow, requires robust demand-side participation. Only in solving the “elasticity issues,” will this be possible.

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