

Lessons and reflections on the smart grid

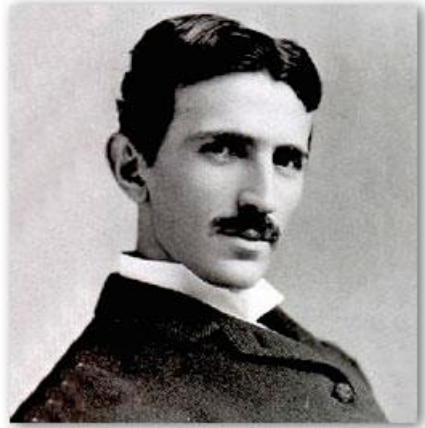
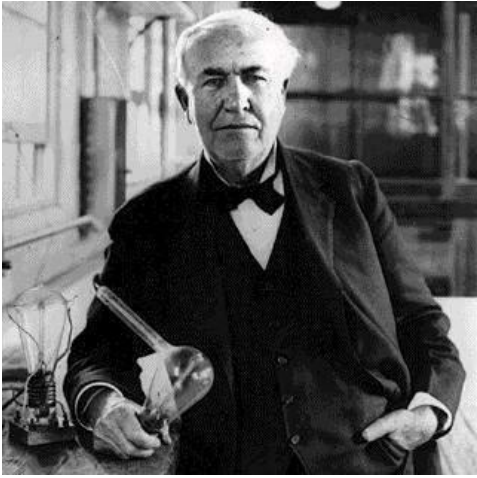
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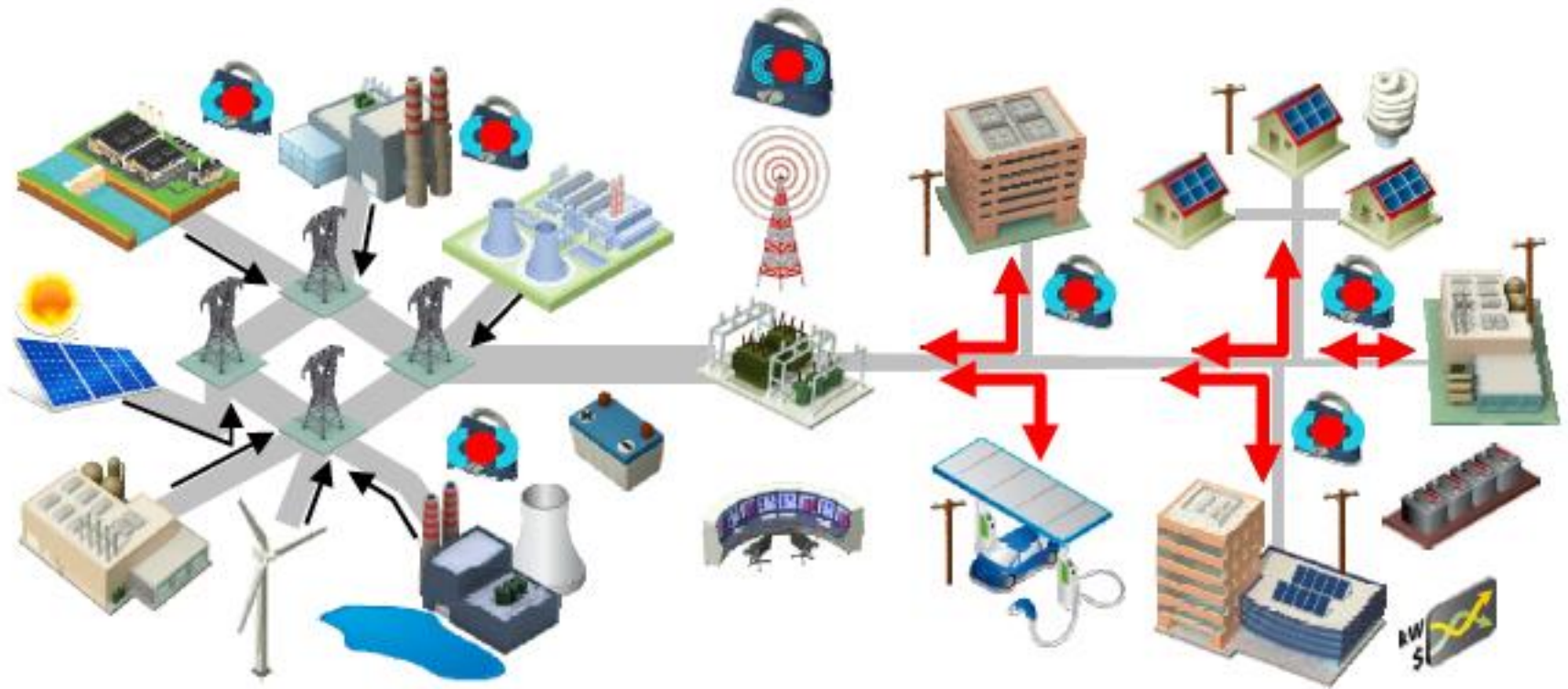
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Smart grid schematic – physical and transactive



Source: EPRI (2011)

Enables move from
closed & centralized
to
open & distributed

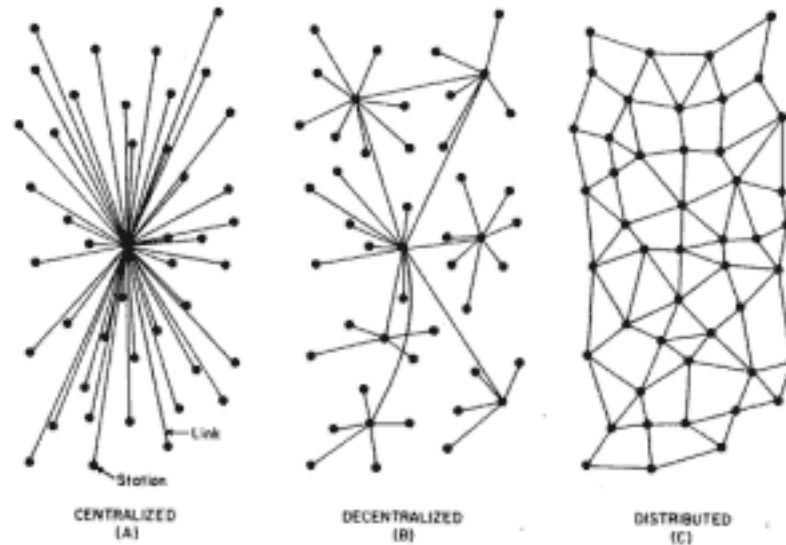


FIG. 1 - Centralized, Decentralized and Distributed Networks

How does digital technology change this landscape economically?

- Cost of providing reliable transmission and distribution
- New, different value propositions to consumers
- Paying for smart grid investments
 - Who decides which investments to make?
 - Who pays the costs?
 - How to weigh operational, environmental, consumer benefits
- Changing business models in the industry

SG effects on costs of reliable T&D

Smart Grid Costs and Benefits Summary

SECTION	COST CATEGORY	COST PER YEAR PER HOUSEHOLD
5.0	Total Estimated Cost (over a 15-year period)	<u>~\$400</u>
	▪ Clean power supply investment	\$80
	▪ Transmission and distribution investment	\$150
	▪ End-use investment, including local power	\$165
SECTION	BENEFITS CATEGORY	VALUE PER YEAR PER HOUSEHOLD
6.0	Total Estimated Savings (excluding security and safety)	<u>~\$1,200</u>
	▪ Direct bill savings (including smaller rate increases)	\$585
	▪ Indirect benefits (e.g., reduced economic losses and deaths)	\$400
	▪ Future revenue (e.g., from providing grid services)	\$250

Information on calculations for this table are included in Sections 5 and 6 of this research paper.

Source: Galvin Electricity Initiative (2012)

Table 3: Estimated Annual Grid Modernization Costs* per Residential Household

SECTION	TECHNOLOGY	ESTIMATED COST PER HOUSEHOLD, \$/YEAR
Clean Power Supply Investment		~\$80
Power Delivery Investment		~\$150
5.2.1	Transmission and Area Distribution	\$12
5.2.2	Local Distribution System or Microgrid Improvements**	\$37
5.2.2.1	Local Substation Automation	\$25
5.2.2.2	Circuit Loops with Smart Switches	\$25
5.2.2.3	Undergrounding Local Cables	\$50
End-Use Investment		~\$165
5.3.1	Local Clean Power Supply	\$46
5.3.2	Smart Meters	\$20
5.3.3	Home Automation	\$100
Approximate Annual Cost		~\$400 / year

Source: Illinois Institute of Technology. (2010). *Perfect Power at IIT* and Gellings, C. (2011). *Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid*. Palo Alto: Electric Power Research Institute.

*This costs represent capital cost amortized over a 15-year period.

**System investment categories based on EPRI report referenced above.

Table 6: Summary of Estimated Annual Savings per Residential Household

SECTION	CATEGORY	ANNUAL SAVINGS/YR.
<u>6.1</u>	<u>Direct bill savings (including avoided rate increases)</u>	<u>\$585</u>
6.1.1	Electricity consumption savings	\$125
6.1.2	Dynamic pricing, time-of-use savings and shifting peak demand	\$110
6.1.3	Avoided new capacity costs	\$130
6.1.4	Improved generation efficiencies	\$200
6.1.5	Reduced transmission and distribution losses	\$20
<u>6.2</u>	<u>Indirect savings</u>	<u>\$400</u>
6.2.1	Improved reliability and power quality	\$400
<u>6.3</u>	<u>Future revenue potential</u>	<u>\$250</u>
6.3.1	Revenue for providing electricity and ancillary services	\$140
6.3.2	Emission reduction credits	\$110
TOTAL BENEFIT		\$1,200
6.4	Public health, safety and homeland security	Significant

See Appendix D: Benefit Calculations, for information on how these numbers were derived.

New, different consumer value propositions

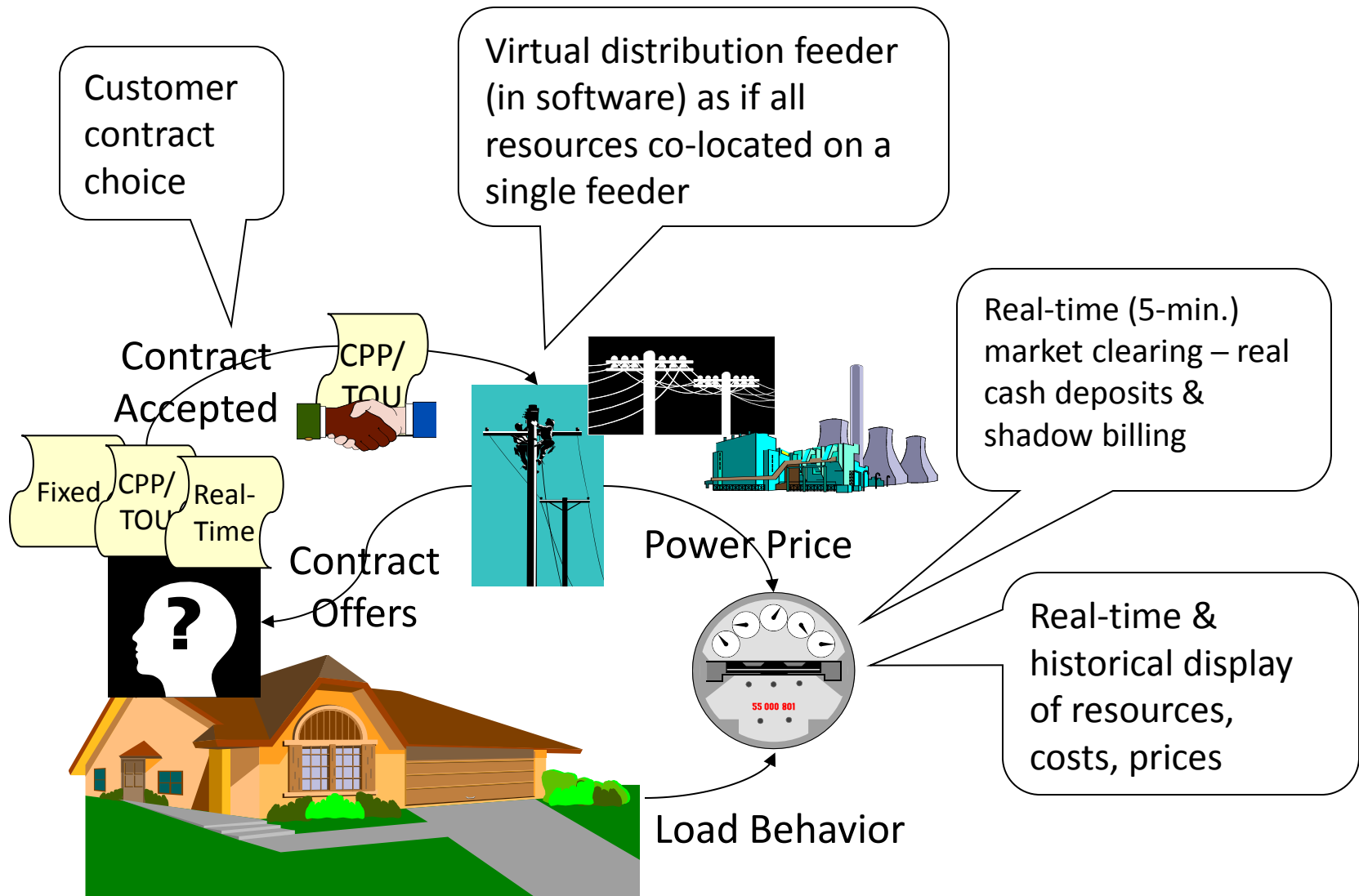
- ... because the value proposition is not only the kwh
- Product differentiation
 - Make more money by selling less power is possible
 - Conservation, satisfying green preferences
 - Examples
 - TOU
 - Dynamic pricing
 - Time differentiated: RTP, CPP, PTR, VPP
 - Green/grey mix
 - Service bundles – home entertainment, home security, home health care
 - Recall our previous discussions of price discrimination and its mutual benefits to consumers and producers
- Digital technology enables automation – reduces transaction costs

Case study: GridWise
Olympic Peninsula
Demonstration Project



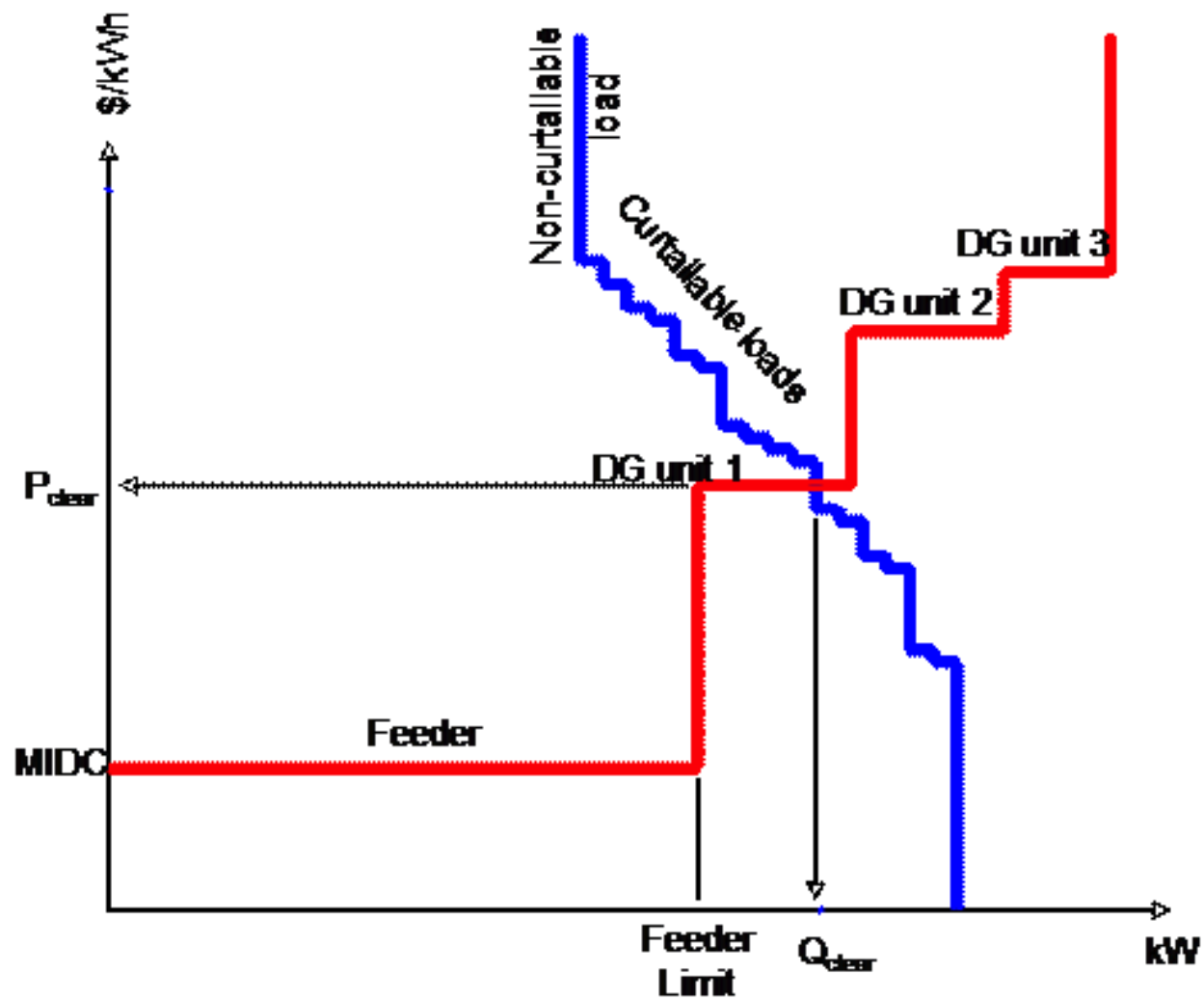


Testing Market-based Customer Incentives in a Transactive Network



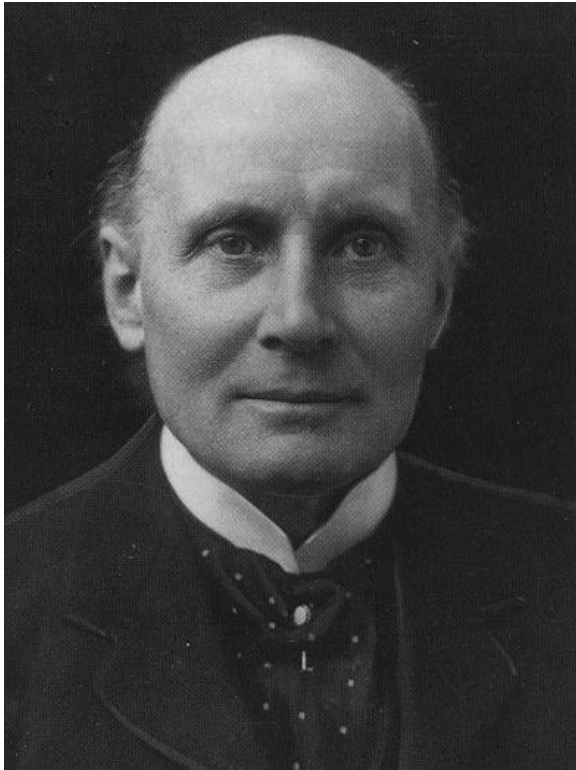
GridWise testbed contract choice field experiment, April 2006-March 2007

- Chassin & Kiesling (2008), Hammerstrom et. al. (2008) for more details
- 116 broadband-enabled households chose among three contracts: Fixed (n=30), TOU (n=31), RTP (n=30)
- Control group (n=25) got transactive technology (PCT, water heater) but did not participate in contract experiment
 - Issue: selection bias due to lack of randomization across treatments
- RTP market clearing
 - 5-minute intervals, with price-responsive appliances & ability to automate decisions
 - Designed as a double auction
 - **First ever use of a double auction in a residential retail electricity market**



Overall project results

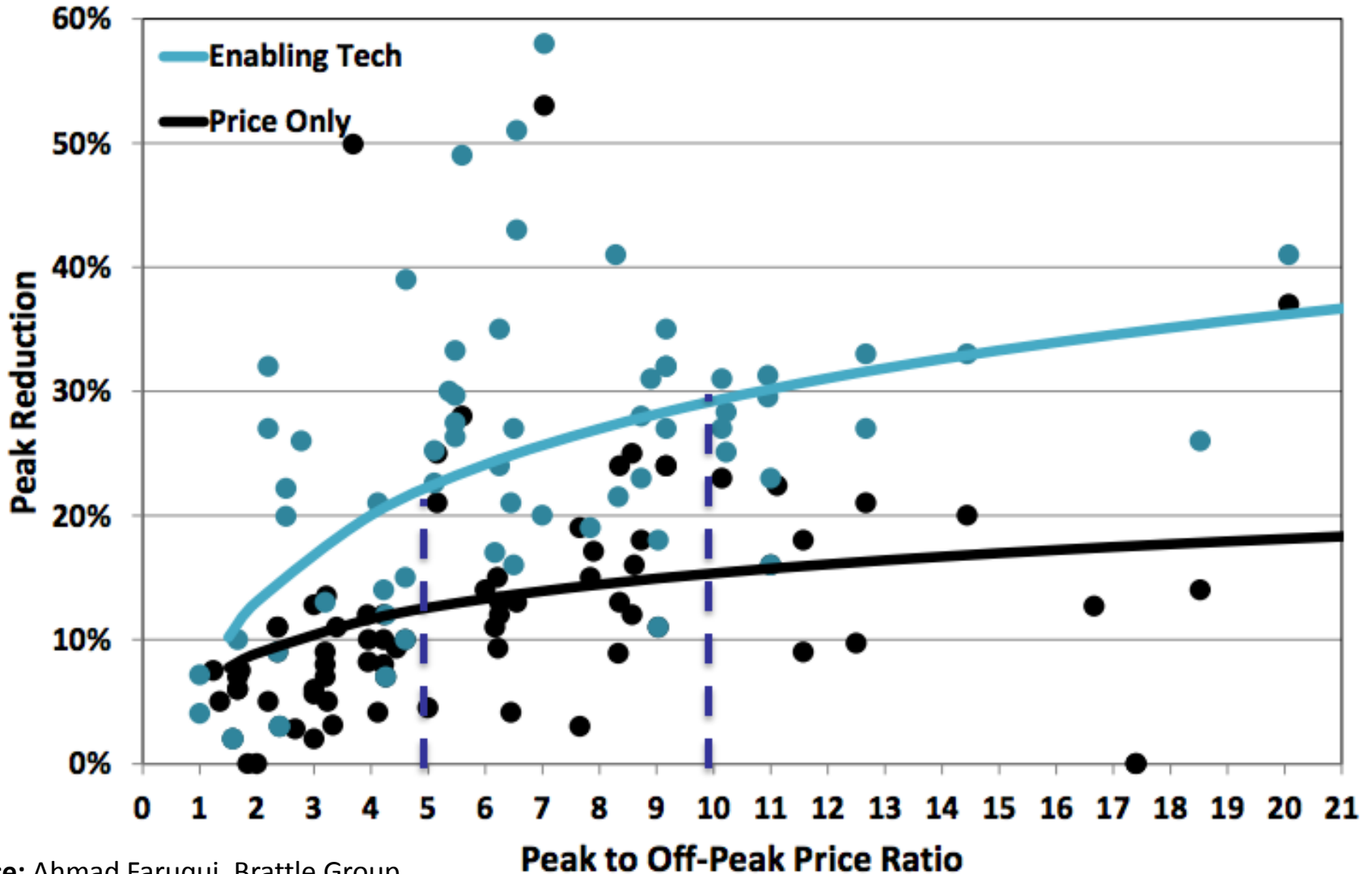
- Automation reduced the transaction costs for individual response to price signals
 - High customer satisfaction *ex post*
- Customer expenditure savings
 - 10% on average
 - Savings highest for RTP customers, then TOU, then fixed, then control
- Changes in consumption: RTP little, TOU 20% reduction; difference could be result of the bidding algorithm of the devices of the RTP consumers
- Dynamic pricing & TOU led to peak demand reduction of 15% on average, rising to 50% during extreme weather
- Implied reduction in wholesale electricity prices
- If extrapolated nationally, can lead to avoided investment in generation, transmission, and distribution infrastructure of \$70 billion over 20 years



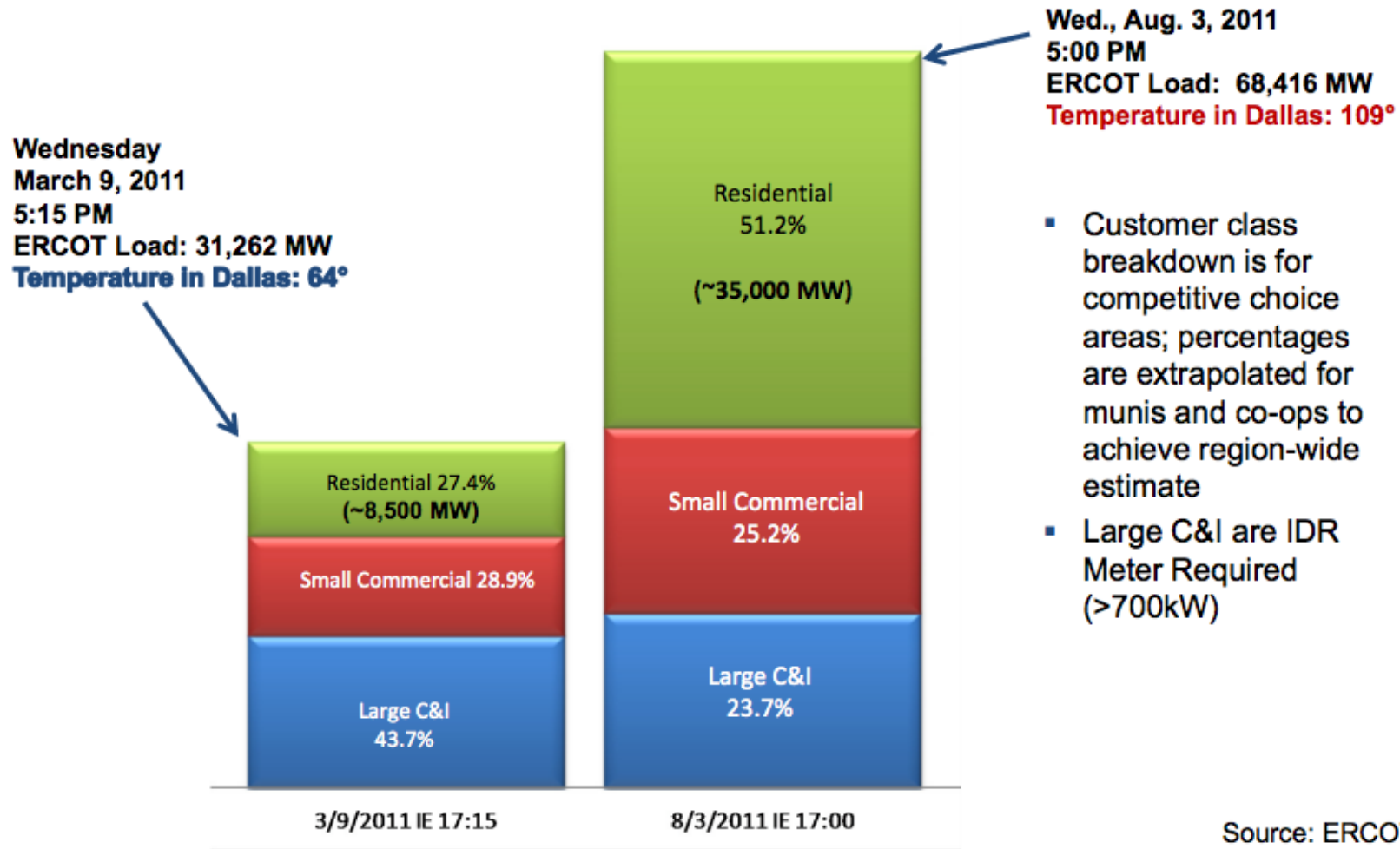
“Civilization advances
by extending the
number of important
operations which we
can perform without
thinking of them.”

-Alfred North
Whitehead

Results dynamic pricing meta-analysis, Faruqui et. al. (2013)



In aggregate, residential DR can have a big impact – Texas potential



Source: Ahmad Faruqui, Brattle Group

Source: ERCOT

Paying for SG investments

- Determination of benefits – to whom?
 - Decreased cost of T&D
 - Increased reliability of D
 - Value of consumer choice & product differentiation
 - Environmental benefits
- Bastiat – the seen and the unseen



How could SG change distribution business models?

- Apply Coase: SG tech => reduced transaction costs, reduced economies of scale & scope => increased potential feasibility & value of retail competition
- Digital technology enables
 - More transparent and timely information
 - Automation of human preferences and decisions
- Retail function not a natural monopoly

Innovation and dynamic value creation occurs through experiments

- Recall NIE insights we've discussed all week – Cognitive reality, incomplete foresight, information, and knowledge
- Recall our double auction – Rivalrous competitive markets create value because they are processes of experimentation and discovery (by both producers and consumers)
- Recall Schumpeter – value creation and economic growth occur through creative destruction, new products and services, new business models, usually from new entrants (including from different industries)
- Enabling experiments in electricity
 - Within VI regulated contexts
 - Pilot projects
 - Microgrids
 - **Reduce entry barriers to retail competition**

Persistent regulatory entry barriers

- Example from retail electricity: incomplete regulated incumbent exit from retail market
 - Incumbent default service provider (except for Texas)
 - Specification of product characteristics and market boundaries in the tariff
- Apply an insight from the AT&T divestiture: failure to quarantine the monopoly
 - US v. AT&T: regulated, vertically-integrated monopoly having anti-competitive downstream effects by leveraging its regulated status
 - Bell Doctrine/Baxter's Law
 - Theory of competition: neoclassical + NIE

Some (provocative) regulatory implications

- How to quarantine the monopoly/where to draw the line?
- How to structure the funding of rate-based investments
- Digital technology depreciation mismatch with traditional “used & useful” long-lived mechanical assets
- Evolving from rate determination to consumer protection
- Technology enables more consumer self-protection, more distributed personal control and management of individual choices of price, quantity, qualities

Connect back to Doug's discussion of Internet

- The electric power industry has been *slow* to adopt many aspects of the smart grid (e.g., distributed operations)
 - Uncertainty on setting the incentives correctly
 - Very similar to the transition of the PSTN to the Internet
 - However, PSTN was an underlay for the Internet; no clear that power grid has analogy
- Lessons to be learned from the Internet
 - Intelligence at the edge
 - Distributed and open design
 - Architecture matters (getting the security right)

Evolution toward open, distributed control & intelligence

- The emergence of the IP-based broadband network was *disruptive* to the traditional telephone industry (in at least three ways)
 - Shifted *intelligence* and hence control of *service creation* from inside the network to the edge (“Intelligent Network” – key PSTN service asset)
 - Provided a much more *powerful platform* that is capable of handling not just voice but a rich combination of content
 - *Undermined* traditional cost/pricing, jurisdictional and regulatory models
- *Open* architectures facilitate service creation and creates opportunities for *rapid innovation*
 - Customers at the edge not only *consume* services and content but increasingly *create* them as well
 - Despite trend toward openness, services and content offered by platform providers inevitably raises issues of *interoperability, interconnection and potential discrimination*
 - *Proprietary* approaches, while offering short term advantages, can lead to long term disadvantages including vendor lock-in

Some challenges

- Evolution is inevitable – it will become smarter (digital, two-way, measured, predictive)
 - How does this affect consumers?
 - Will consumers have a role, or even any input?
- Status quo bias and ability or desire to effect change in the face of uncertainty
- Desirability or relevance of the uniformity principle
- Data ownership & property rights
- Privacy