ELECTRICITY MARKET DESIGN

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Electricity Market Design Panel

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Electricity Market Fundamentals

A core challenge for all electricity systems is between monopoly provision and market operations. Electricity market design depends on critical choices. There is no escape from the fundamentals.

Integrated Monopoly	Competitive Markets
• Mandated	• Voluntary
• Closed Access	• Open Access
• Discrimination	• Non-discrimination
• Central Planning	• Independent Investment
• Few Choices	• Many Choices
• Spending Other People's Money	• Spending Your Own Money
• Average Cost Pricing	• Marginal Cost Pricing

A Key Market Design Objective

Supporting the Solution: Given the prices and settlement payments, individual optimal behavior is consistent with the aggregate optimal solution.

A passing reflection on history reinforces the view that there is great uncertainty about energy technology choices for the future. There are many examples of both bad and good surprises.

TVA's nuclear plant auction set for November

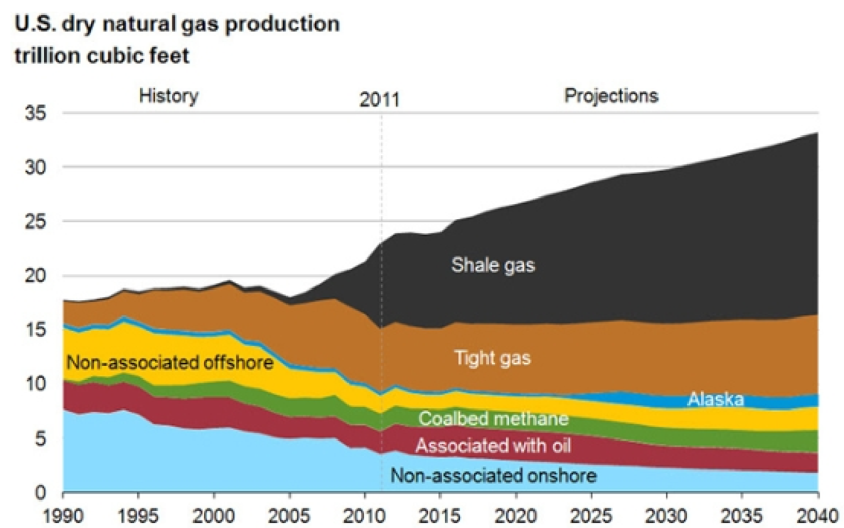
"The Tennessee Valley Authority, in apparently a first in the US power industry, plans to auction its unfinished Bellefonte nuclear plant in Alabama on November 14 in what amounts to a "fire sale" of epic proportions.

Over more than four decades, an estimated $6 billion was pumped into the project imagined at a time of far different economic and electricity projections and expectations. Bellefonte's minimum asking price — $36.4 million."

(Megawatt Daily, October 18, 2016, p. 3)

U.S. Shale Miracle:

Once the technology crossed the market threshold, deployment was both large and rapid.



Source: U.S. Energy Information Administration, *Annual Energy Outlook 2013 Early Release*

Good wholesale electricity market design is necessary to provide open access with non-discrimination principles that encourage entry and innovation.

The case of electricity restructuring presents examples of fundamental problems that challenge regulation of markets.

- **Marriage of Engineering and Economics.**
  - **Loop Flow.**
  - **Reliability Requirements.**
  - **Incentives and Equilibrium.**

- **Devilish Details.**
  - **Retail and Wholesale Electricity Systems.**
  - **Market Power Mitigation.**
  - **Coordination for Competition.**

- **Jurisdictional Disputes.**
  - **US State vs. Federal Regulators.**
  - **European Subsidiarity Principle.**

Electricity restructuring presents twin challenges with a broad theme.

- **Create an effective electricity market design with associated transmission access rules.**
  - An electricity market must be designed.
  - The market cannot solve the problem of market design.
  - Incentives should drive decisions and innovation.

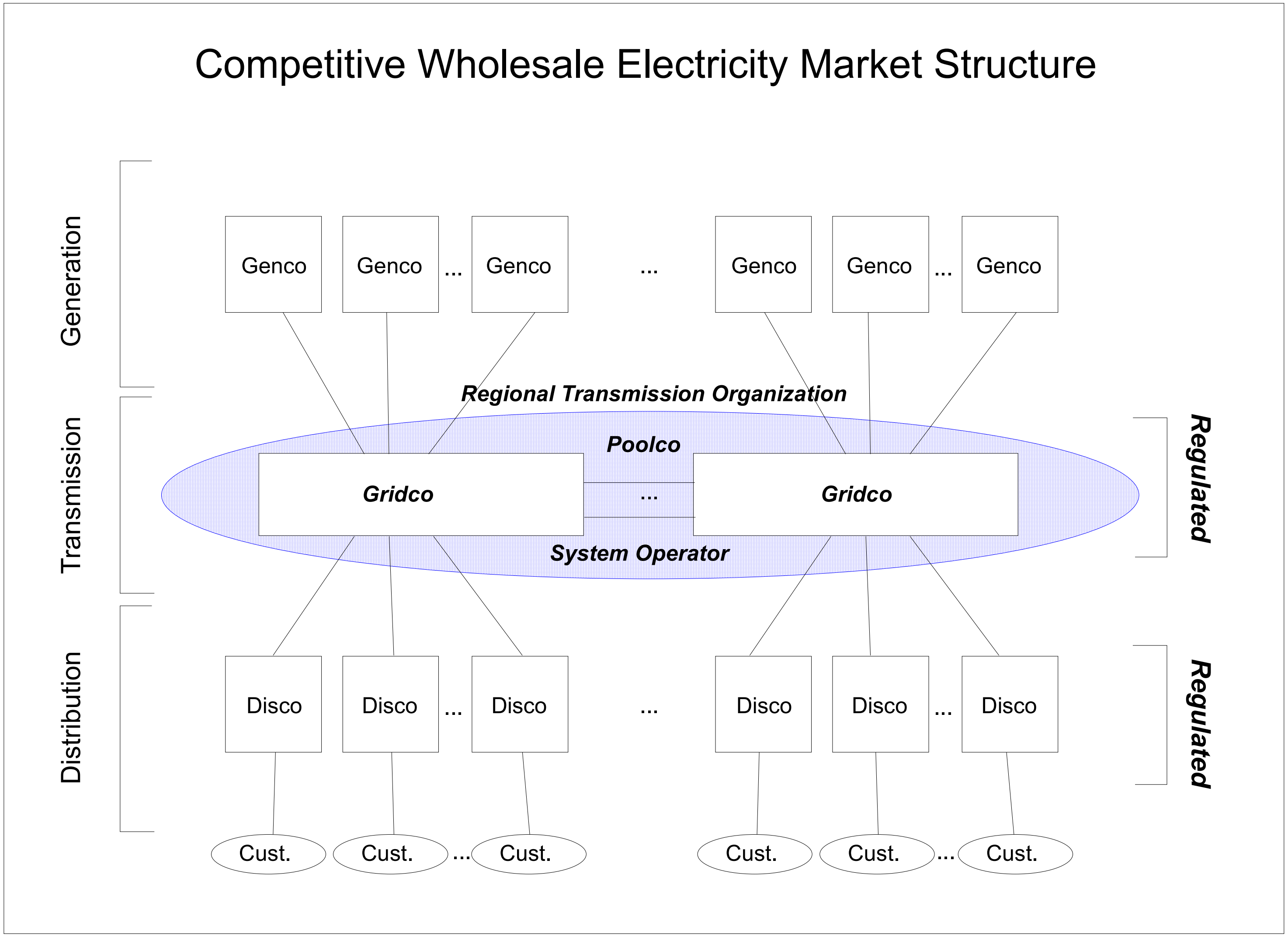
- **Provide compatible market interventions to compensate for market imperfections.**
  - Market imperfections exist under the best designs.
  - Network interactions make the obvious answers wrong or even dangerous.
  - Poor market design makes interventions more necessary, more common, and more difficult.

There is a close connection between the twin challenges, and the slippery slope of intervention can lead to an electricity market that may be worse than the system it was to replace.

If the central planners (or regulators) know what to do, then do it.

But if true, what is the need for electricity restructuring and markets?

The original arguments for greater reliance on markets emphasized the effects of non-utility generators and the reduction or elimination of the conditions for natural monopoly in generation.



The U.S. experience illustrates successful market design and remaining challenges for both theory and implementation.

- **Design Principle: Integrate Market Design and System Operations**

  Provide good short-run operating incentives.

  Support forward markets and long-run investments.

- **Design Framework: Bid-Based, Security Constrained Economic Dispatch**

  Locational Marginal Prices (LMP) with granularity to match system operations.

  Financial Transmission Rights (FTRs).

- **Design Implementation: Pricing Evolution**

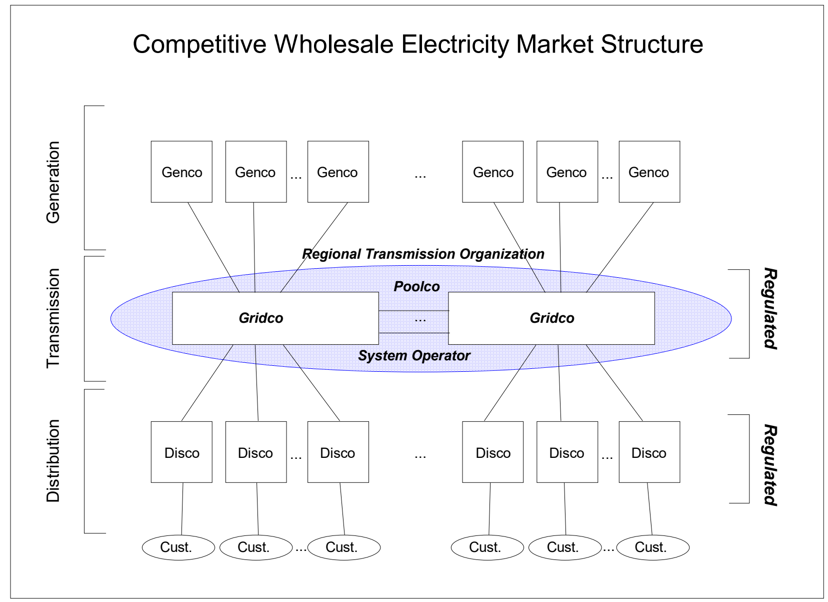
  Better scarcity pricing to support resource adequacy.

  Unit commitment and lumpy decisions with coordination, bid guarantees and uplift payments.

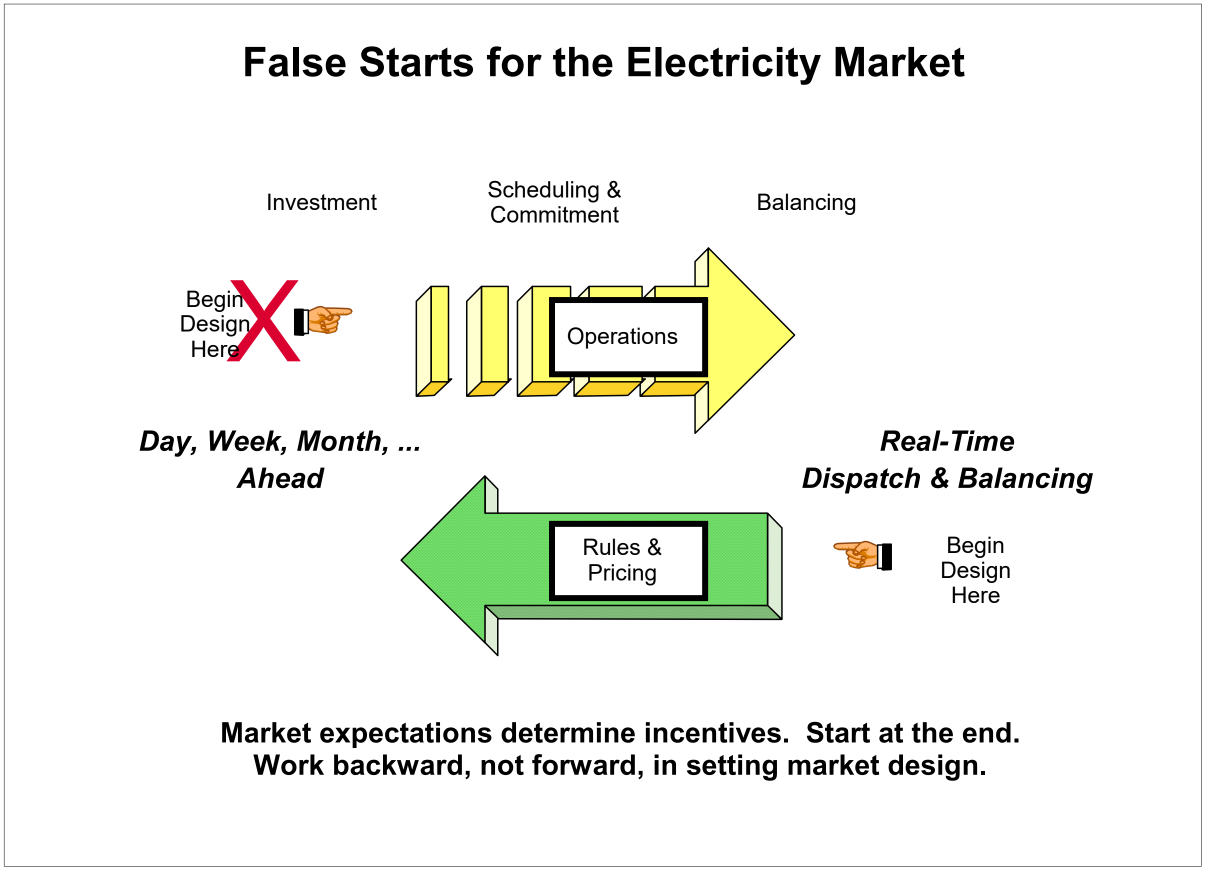
- **Design Challenge: Infrastructure Investment**

  Hybrid models to accommodate both market-based and regulated transmission investments.

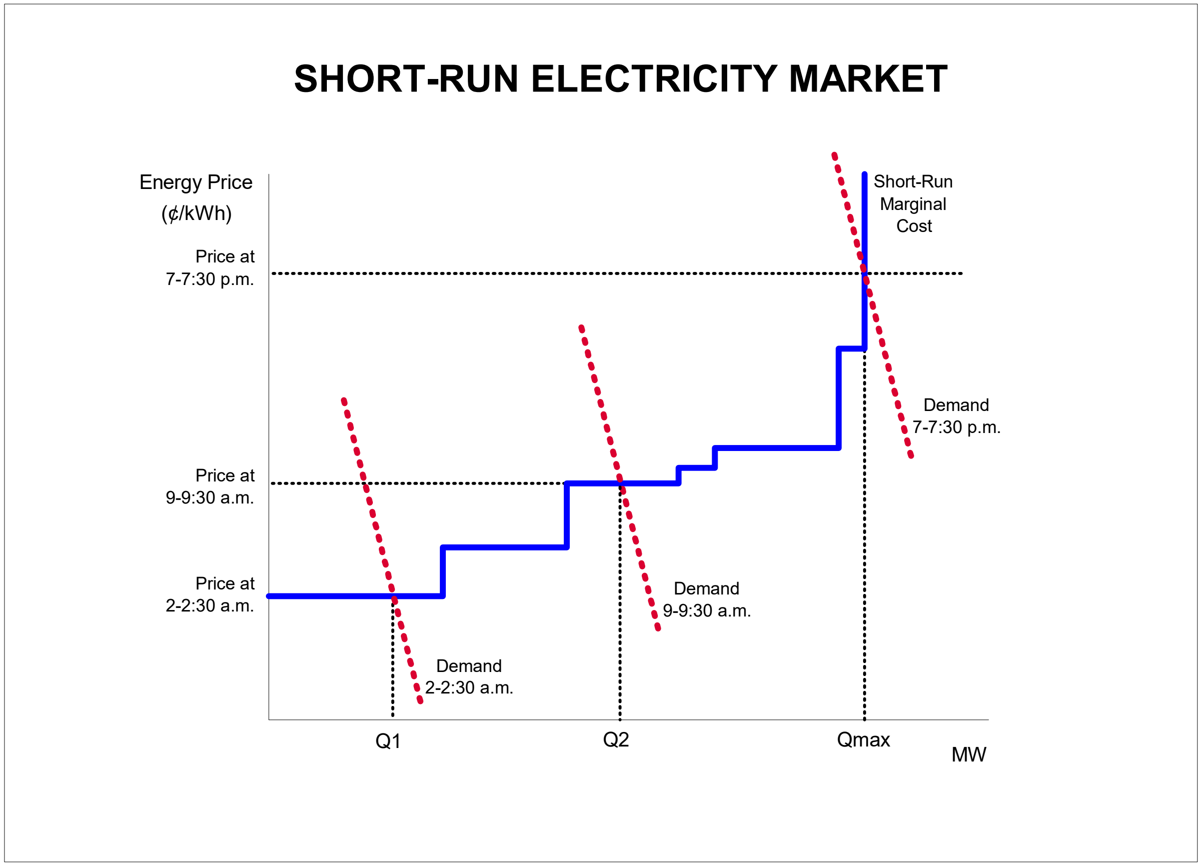
  Beneficiary-pays principle to support integration with rest of the market design.



The solution to open access and non-discrimination inherently involves market design. Good design begins with the real-time market and works backward. A common failure mode starts with the forward market, without specifying the rules and prices that would apply in real time.



An efficient short-run electricity market determines a market clearing price based on conditions of supply and demand balanced in an economic dispatch. Everyone pays or is paid the same price.



The independent system operator provides a dispatch function. Three questions remain. Just say yes, and the market can decide on the split between bilateral and coordinated exchange.

- **Should the system operator be allowed to offer an economic dispatch service for some plants?**

The alternative would be to define a set of administrative procedures and rules for system balancing that purposely ignore the information about the costs of running particular plants. It seems more natural that the system operator considers customer bids and provides economic dispatch for some plants.

- **Should the system operator apply marginal cost prices for power provided through the dispatch?**

Under an economic dispatch for the flexible plants and loads, it is a straightforward matter to determine the locational marginal costs of additional power. These marginal costs are also the prices that would apply in the case of a perfect competitive market at equilibrium. In addition, these locational marginal cost prices provide the consistent foundation for the design of a comparable transmission tariff.

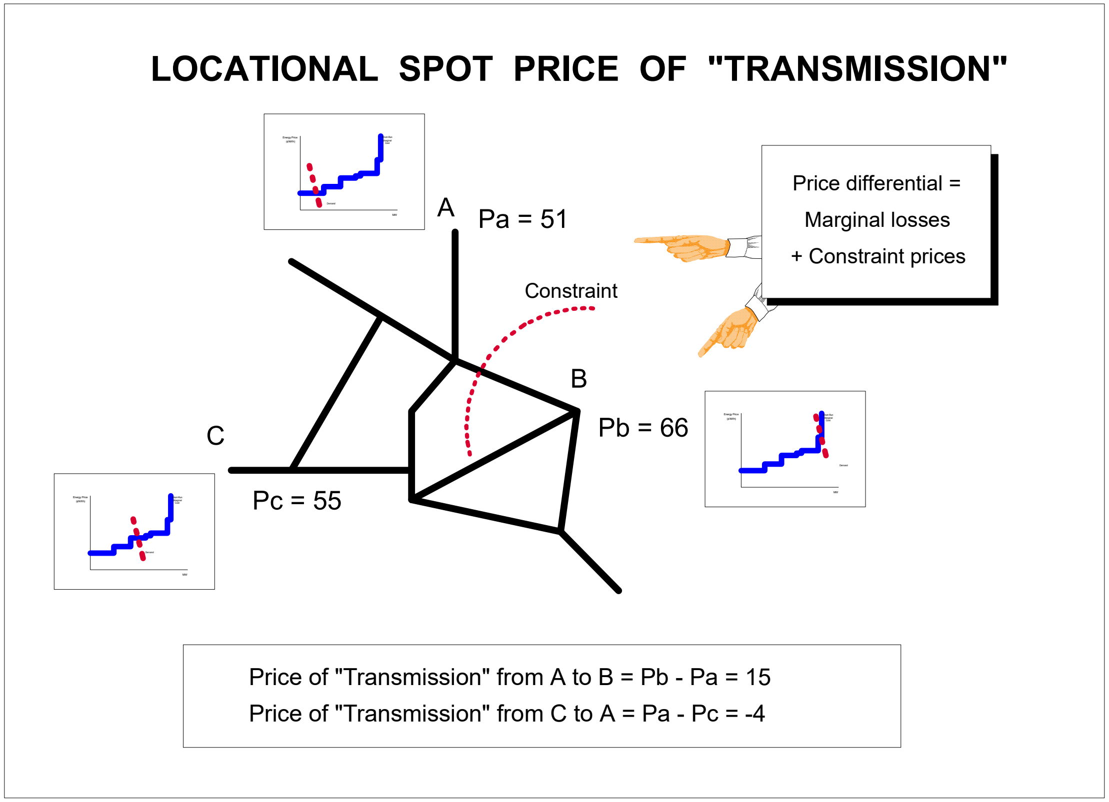
- **Should generators and customers be allowed to participate in the economic dispatch offered by the system operator?**

The natural extension of open access and the principles of choice would suggest that participation should be voluntary. Market participants can evaluate their own economic situation and make their own choice about participating in the operator's economic dispatch or finding similar services elsewhere.

The natural extension of a single price electricity market is to operate a market with locational spot prices. (Schweppe, Caramanis, Tabors, & Bohn, 1988)

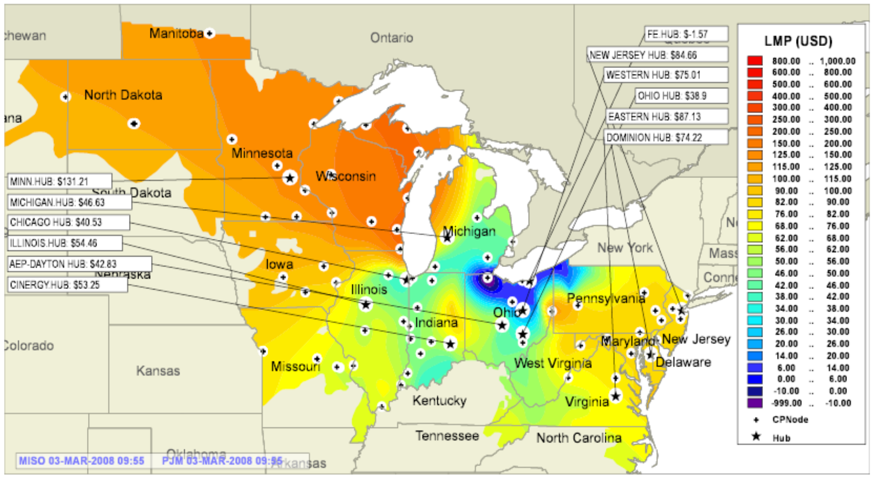
- It is a straightforward matter to compute "Schweppe" spot prices based on marginal costs at each location.

- Transmission spot prices arise as the difference in the locational prices.

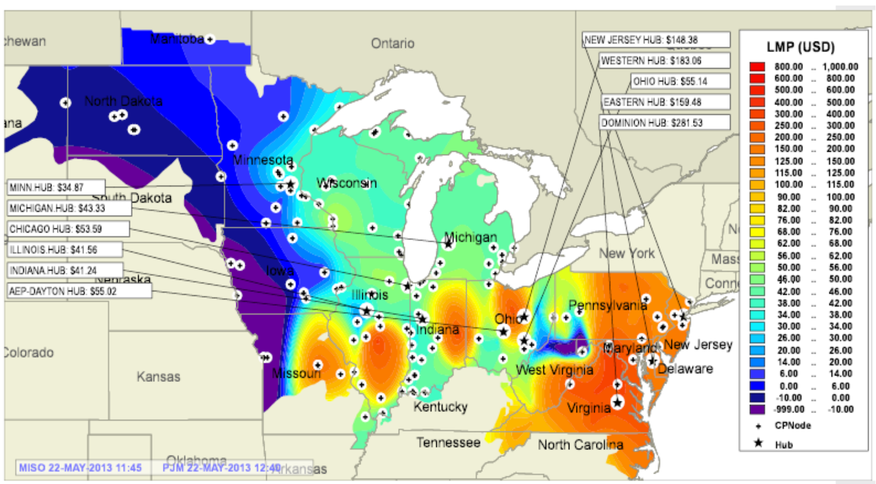


NETWORK INTERACTIONS Locational Spot Prices

RTOs operate spot markets with locational prices. For example, PJM updates prices and dispatch every five minutes for over 12,000 locations. Locational spot prices for electricity exhibit substantial dynamic variability and persistent long-term average differences.



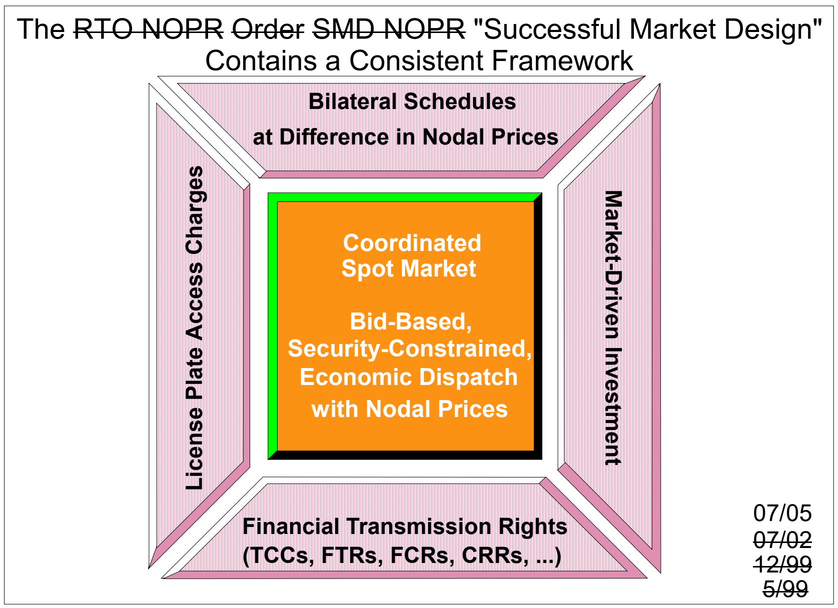
Minnesota Hub: $131.21/MWh. First Energy Hub: $-1.57/MWh. March 3, 2008, 9:55am



Missouri MPS -$71.25, Dominion Hub $281.53. May 22, 2013, 12:40pm.

From MISO-PJM Joint and Common Market, ++http://www.jointandcommon.com

The example of successful central coordination, ~~CRT, Regional Transmission Organization (RTO) Millennium Order (Order 2000) Standard Market Design (SMD) Notice of Proposed Rulemaking (NOPR),~~ "Successful Market Design" provides a workable market framework that is working in places like New York, PJM in the Mid-Atlantic Region, New England, the Midwest, California, SPP, and Texas. This efficient market design is under (constant) attack.



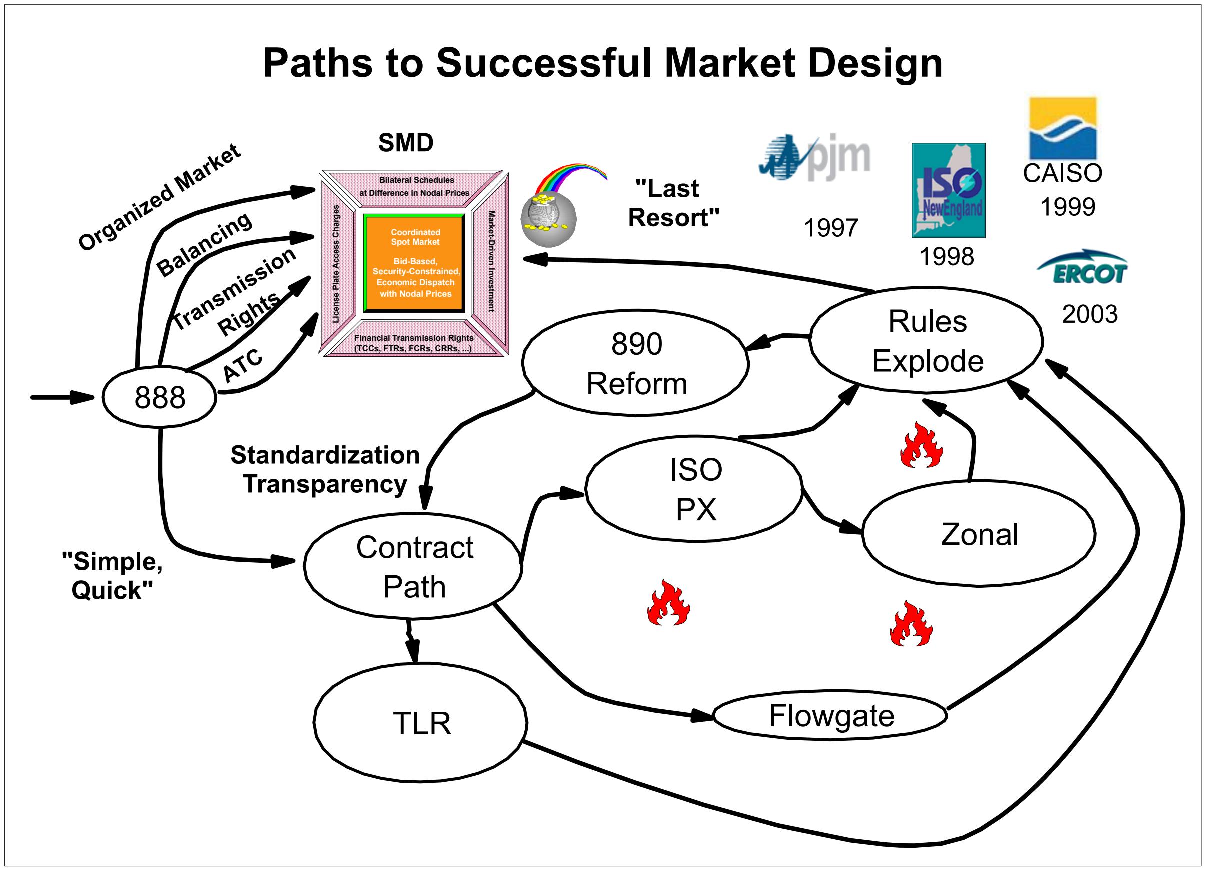
Poolco…OPCO…ISO…IMO…Transco…RTO…ITP…WMP…: "A rose by any other name …"

"Locational marginal pricing (LMP) is the electricity spot pricing model that serves as the benchmark for market design – the textbook ideal that should be the target for policy makers. A trading arrangement based on LMP takes all relevant generation and transmission costs appropriately into account and hence supports optimal investments." (International Energy Agency, 2007)

This is the only model that can meet the tests of open access and non-discrimination.

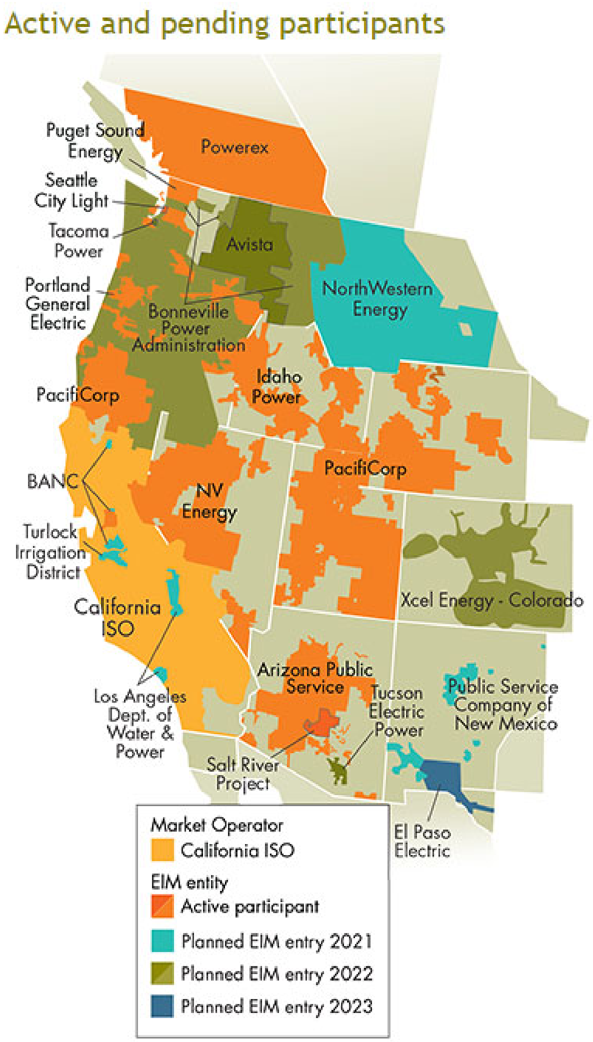
Supporting the Solution: Given the prices and settlement payments, individual optimal behavior is consistent with the aggregate optimal solution. Anything that upsets this design will unravel the wholesale electricity market. The basic economic dispatch model accommodates the green energy agenda, as in the expanding Western Energy Imbalance Market (EIM).

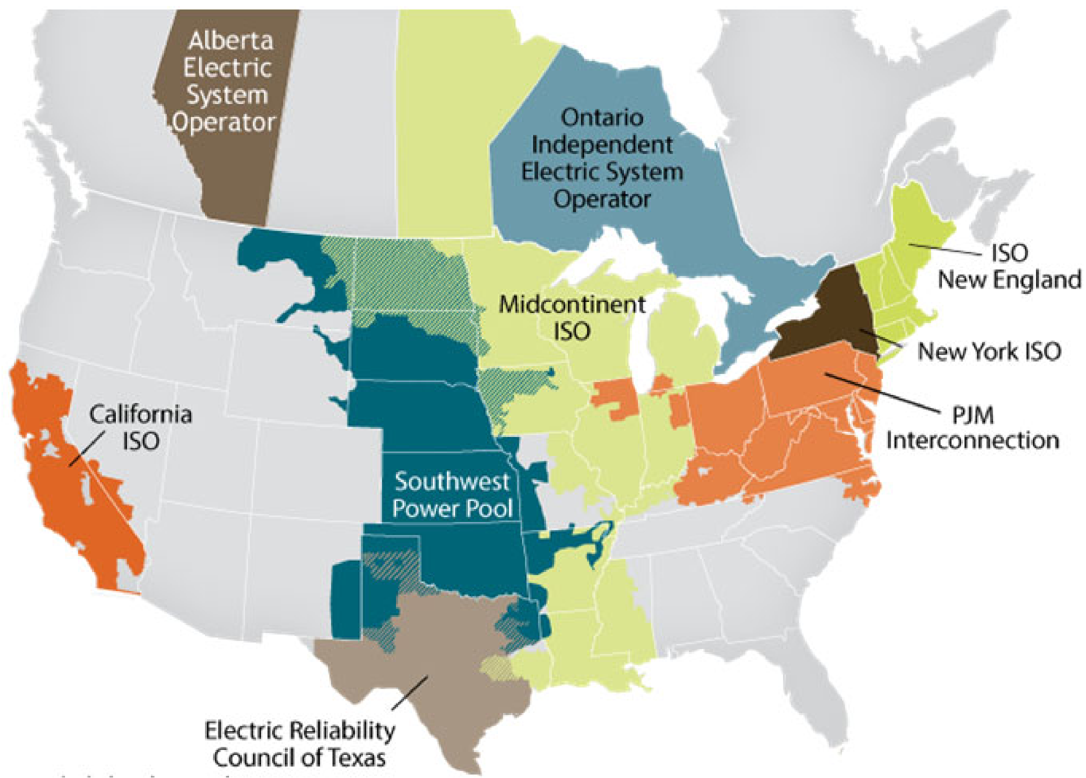
The path to successful market design can be circuitous and costly. The FERC "reforms" in Order 890 illustrate "path dependence," where the path chosen constrains the choices ahead. Early attempts with contract path, flowgate and zonal models led to design failures in PJM (`97), New England (`98), California (`99), and Texas (`03). Regional aggregation creates conflicts with system operations. Successful market design integrates the market with system operations.



The basic model covers the existing Regional Transmission Organizations in the United States and is expanding through the Western Energy Imbalance Market. (www.westerneim.com)

(IRC Council and CAISO maps)



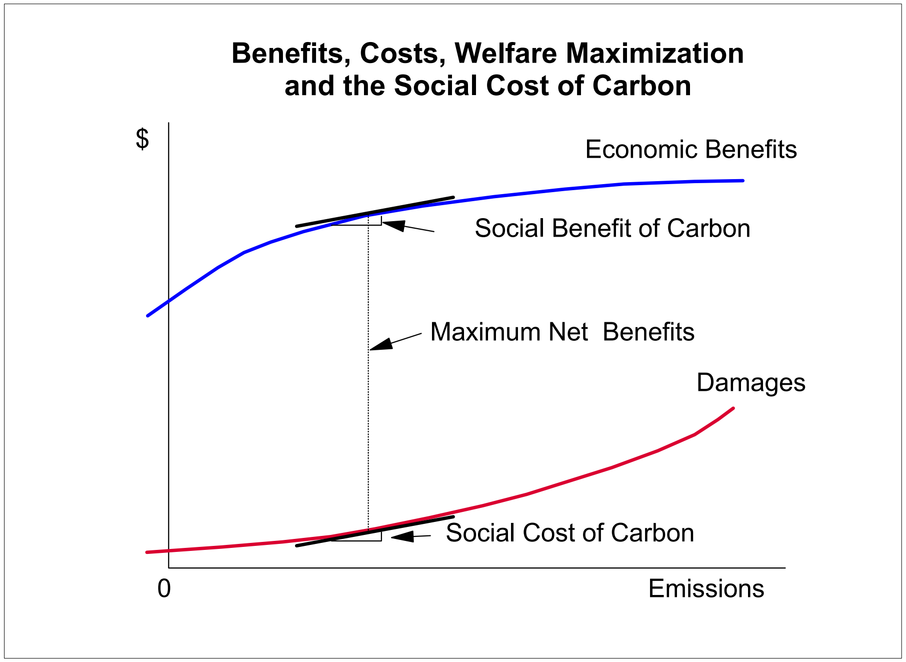


Climate and Energy Policy

The challenges of climate change present a 'wicked problem' that is difficult to solve because of incomplete, contradictory, and changing requirements. The scale is global, the duration covers many generations into the future, and the uncertainties can seem overwhelming.

Overview

- **The Science helps identify the challenges and opportunities.**
- **The Science does not and cannot tell us what to do.**
- **There are tradeoffs and this points to the need for cost-benefit analysis.**
- **One guidepost is the Social Cost of Carbon that provides a standard for what to do and how much is enough.**
- **There are many critical uncertainties.**
- **A central problem is the continuing debate about discount rates.**



- **The climate policy choices will interact with everything else, including the design and operation of energy markets.**

The National Academy of Sciences identified two main barriers and emphasized two "overarching recommendations." (National Academy of Sciences, *The Power of Change: Innovation for Development and Deployment of Increasingly Clean Electric Power Technologies*, Washington D.C., 2016, pp.3-4.) (National Academy of Sciences, 2016)

Barriers

"The committee concluded that there are two significant barriers to accelerating greater penetration of increasingly clean electricity technologies. First, as noted above, the market prices for electricity do not include "hidden" costs from pollution, stemming mainly from negative impacts on human health, agriculture, and the environment. Levels of criteria pollutants declined over the past three decades, but still cause harms. Harms from GHGs are difficult to estimate, but if accounted for in the market, could be considered by consumers. …

The second barrier is that the scale of the climate change challenge is so large that it necessitates a significant switch to increasingly clean power sources. In most of the United States, however, even with a price on pollution, most increasingly clean technologies would lack cost and performance profiles that would result in the levels of adoption required. In most cases, their levelized costs are higher than those of dirtier technologies, and there are significant challenges and costs entailed in integrating them into the grid at high levels. This means that reducing the harmful effects of emissions due to electricity generation will require a broader range of low-cost, low- and zero-emission energy options than is currently available, as well as significant changes to the technologies and functionality of the electricity grid and the roles of utilities, regulators, and third parties. …

…even if the technological and institutional barriers to greater adoption of increasingly clean power technologies were overcome but their prices were not competitive, an adequate scale of deployment would require tremendous public outlays, and in many parts of the world would be unlikely to occur. While learning by doing can lower some costs, deployment incentives are likely to be insufficient as the primary policy mechanism for achieving timely cost and performance improvements."

The Social Cost of Carbon would define the "appropriate price on pollution." Too high or too low would reduce net welfare. Failure to price carbon leads to inefficient policies that impose costs but may have few benefits.

"Subsidies pose a more general problem in this context. They attempt to discourage carbon-intensive activities by making other activities more attractive. One difficulty with subsidies is identifying the eligible low-carbon activities. Why subsidize hybrid cars (which we do) and not biking (which we do not)? Is the answer to subsidize all low carbon activities? Of course, that is impossible because there are just too many low-carbon activities, and it would prove astronomically expensive. Another problem is that subsidies are so uneven in their impact. A recent study by the National Academy of Sciences looked at the impact of several subsidies on GHG emissions. It found a vast difference in their effectiveness in terms of CO_2 removed per dollar of subsidy. None of the subsidies were efficient; some were horribly inefficient; and others such as the ethanol subsidy were perverse and actually increased GHG emissions. The net effect of all the subsidies taken together was effectively zero!"

So in the end, it is much more effective to penalize carbon emissions than to subsidize everything else." (Nordhaus, 2013, p. 266)

"Mufson: ExxonMobil has been facing a revolt by shareholders unhappy with the company's financial performance and its approach to climate change. Is this part of a wave of efforts to push new and maybe difficult responsibilities onto corporations?

Nordhaus: It's just another example of efforts we're expending that are extremely costly and extremely divisive. It takes away valuable analyst time from other more fruitful activities such as pricing fossil fuels at the proper social costs. The movement to have companies measure and disclose their emissions is just an enormous waste of time. If you had a proper price on carbon, we wouldn't have to do that any more than we need companies to do an inventory of their wheat use or silicon use. It's another example of how we're going town a rabbit hole of measures. Even the central banks are getting involved."

(Steven Mufson Nordhaus Interview, Nobel winner's evolution from 'dark realist' to just plain realist on climate change, Washington Post, June 14, 2021.)

Subsidies are growing: RPS, RECs, PTCs, ITCs, DR, ZECs and zero emission targets.

"Subsidies are contagious. Competition in the markets could be replaced by competition to receive subsidies." (Monitoring Analytics, 2017, p. 2)

The DICE model is deterministic. Nordhaus examines some of the effects of uncertainty in terms of the implied SCC today by approximating the impact of uncertainty in the DICE model.

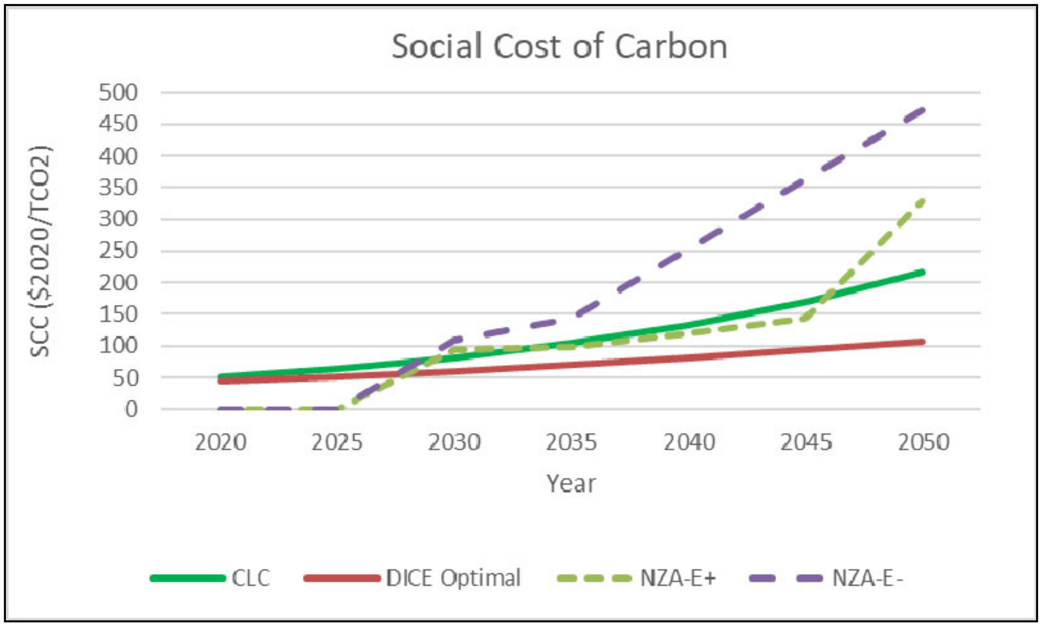
“When uncertainties are accounted for, the expected values of most of the major geophysical variables, such as temperature, are largely unchanged. However, the social cost of carbon is higher (by about 10 percent) under uncertainty than in the best-guess case because of the asymmetry in the impacts of uncertainty on the damages from climate change. … the relative uncertainty is much higher for economic variables than for geophysical variables.” (Nordhaus, 2018, p. 335)

“The ranges of uncertainty for future emissions, concentrations, temperature, and damages are extremely large. However, this does not reduce the urgency of taking strong climate change policies today. When taking uncertainties into account, the desirable strength of policy (as measured by the social cost of carbon or the optimal carbon tax) would increase, not decrease.” (Nordhaus, 2018, p. 335)

“The act-then-learn approach to decisions cannot be fully incorporated into the current DICE uncertainty structure. … I have undertaken a small test case which examines the impact of learning that is delayed until 2050. …. The results of this simplified example indicate that policies are relatively insensitive to late learning, although there is substantial value of learning. The optimal carbon price in the act-then-learn approach is about 6 percent higher than for that of learn-then-act ($36.1/tCO2 rather than $34.2/tCO2 in 2015.” (Nordhaus, 2018, p. 358)

The estimates for the Social Cost of Carbon from the DICE optimization, the CLC policy proposal, and the Net-Zero America cost effective trajectories diverge substantially.

The DICE model computes an optimal trajectory. The Clmate Leadership Council proposal includes a "Gradually Rising Carbon Fee … Carbon Dividends for All Americans … Significant Regulatory Simplification … Border Carbon Adjustment."[1] The Princeton Net-Zero America report sets a 2050 emissions target and estimates the implied marginal cost of emission reduction for a range of trajectories. (Larson et al., 2020, p. 204) The near term estimates are similar, but by 2050 the implied SCCs diverge from substantially from the DICE optimum. (Gollier, 2020)

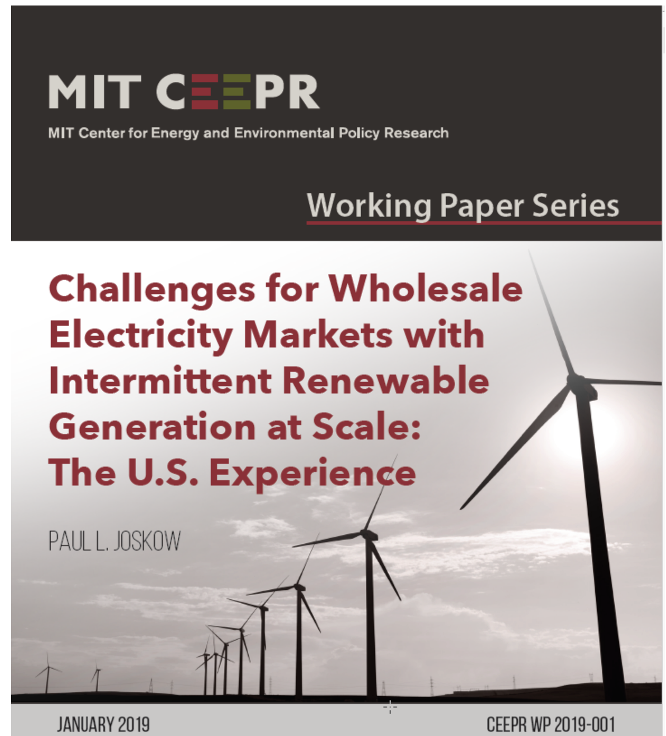


[1] https://clcouncil.org/our-plan/

Electricity Market Design
And
The Green Agenda

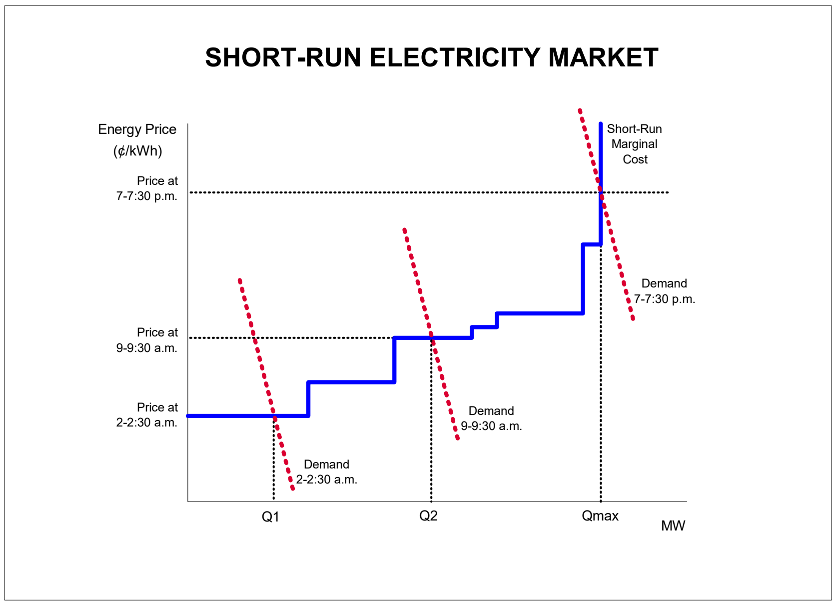
The expansion of intermittent sources and the rise in special subsidies is seen as a threat to efficient electricity market design.

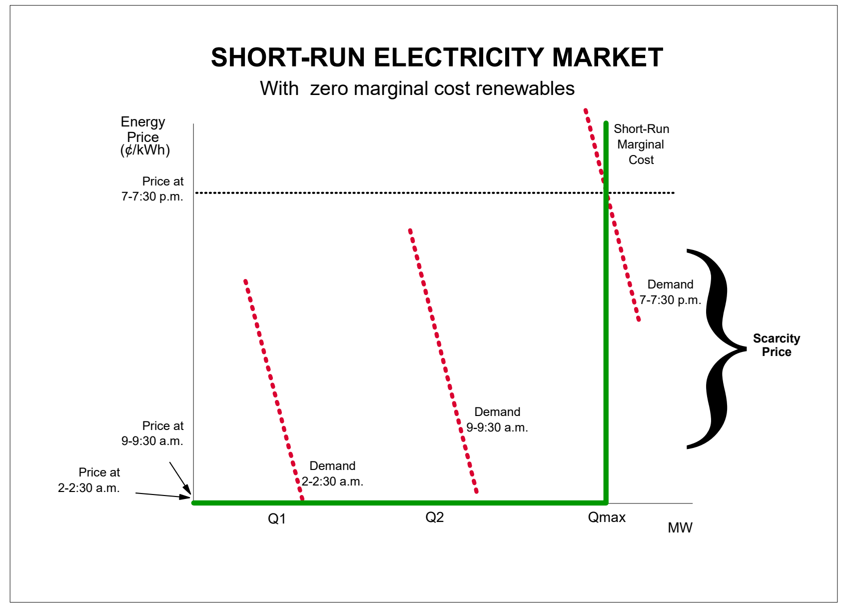
"The supply of intermittent wind and solar generation with zero marginal operating cost is increasingly rapidly in the U.S. These changes are creating challenges for wholesale markets in two dimensions. Short term energy and ancillary services markets, built upon mid-20th century models of optimal pricing and investment, which now work reasonably well, must accommodate the supply variability and energy market price impacts associated with intermittent generation at scale. These developments raise more profound questions about whether the current market designs can be adapted to provide good long-term price signals to support investment in an efficient portfolio of generating capacity and storage consistent with public policy goals. … Reforms in capacity markets and ***scarcity pricing mechanisms*** are needed if policymakers seek to adapt the traditional wholesale market designs to accommodate intermittent generation at scale. However, if the rapid growth of integrated resource planning, subsidies for some technologies but not others, mandated long term contracts, and other expansions of state regulation continues, more fundamental changes are likely to be required in the institutions that determine generator and storage entry and exit decisions." (Joskow, 2019) (emphasis added)



There are several issues such as system strength (Australian Energy Market Commission, 2020) and multi-period pricing (Hua, Schiro, Zheng, Baldick, & Litvinov, 2019) (Biggar & Reza Hesamzadeh, 2022). However, scarcity pricing is a continuing challenge for market design (Hogan, 2013).

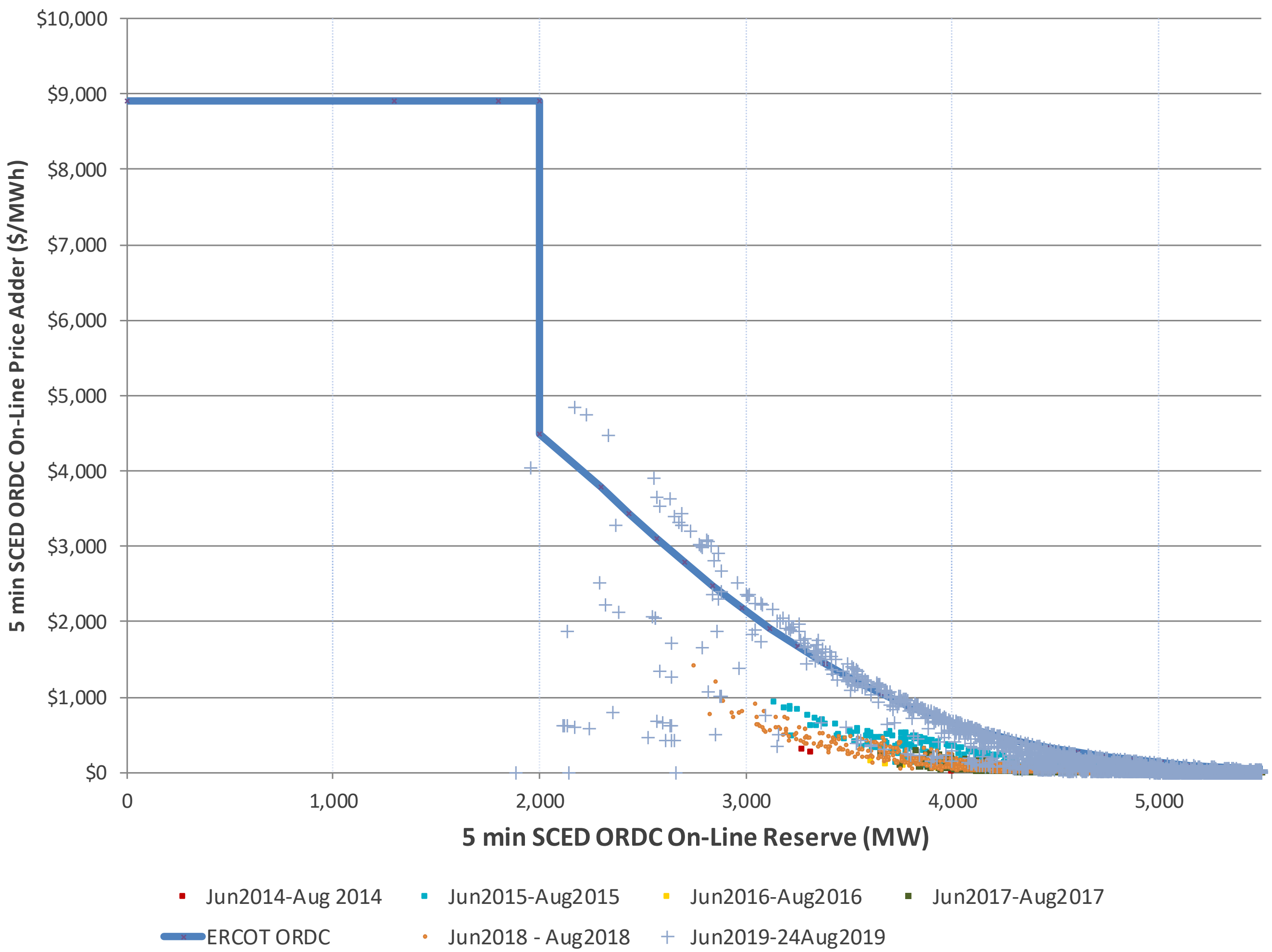
An efficient short-run electricity market determines a market clearing price based on conditions of supply and demand balanced in an economic dispatch. Everyone pays or is paid the same price. The thought experiment of a no-carbon/zero-variable-cost, green energy supply reveals that the basic efficiency principles still apply. The same principles apply in an electric network. (Schweppe et al., 1988) **Storage will be important, but does not change the basic design analysis.** (Korpås & Botterud, 2020)





A key feature would be to increase the importance of scarcity pricing. ERCOT adopted an Operating Reserve Demand Curve in 2014. (Hogan, 2013) **PJM has proposed a series of reforms for energy price formation, motivated in part by the impact of increased penetration of intermittent renewable resources.** (PJM Interconnection, 2017) (PJM Interconnection, 2019) (Federal Energy Regulatory Commission, 2020)

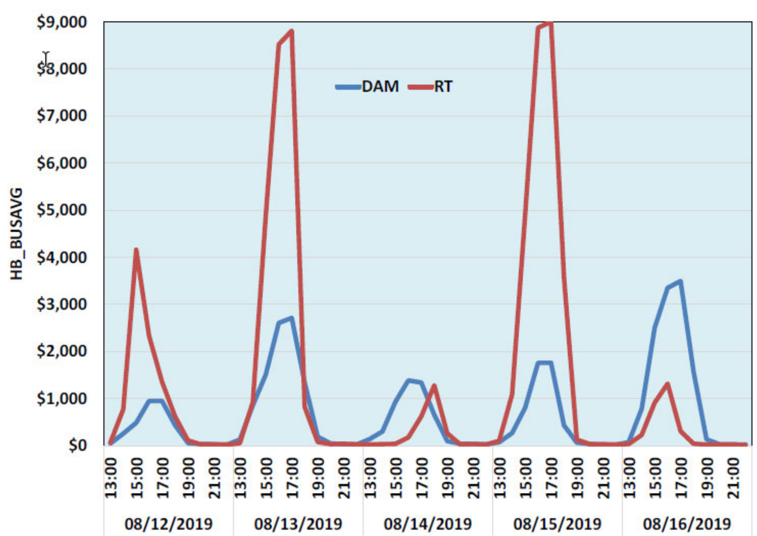
ERCOT launched implementation of the ORDC in in 2014. The summer peak is the most important period. The first five years of results show recent scarcity of reserves and higher reserve prices.



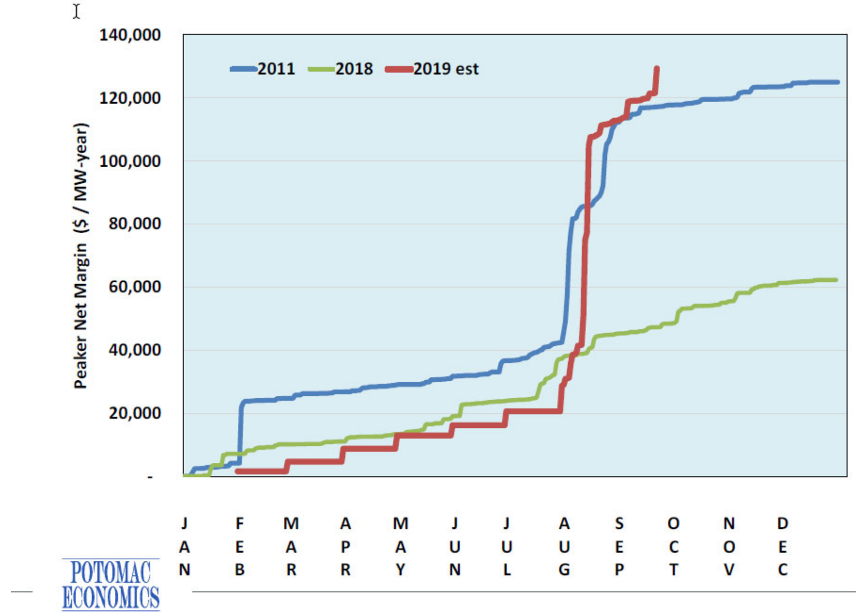
Source: Resmi Surendran, ERCOT, EUCI Presentation, Updated 8/31/2019. The ORDC is illustrative. See also (Hogan & Pope, 2017)

After introduction of the ORDC scarcity prices and the contribution to Peaker Net Margin were low for several years, but this changed in 2019.[2] The PNM target level is $80,000-$95,000/MW-Yr. (Potomac Economics, 2019, p. 112)

Day Ahead vs Real-Time Prices



Peaker net margin in 2019 is the highest ever



2 Beth Garza, "Independent Market Monitor Report," Potomac Economics, ERCOT Board of Directors Meeting Presentation, October 8, 2019.

An ERCOT review of the Summer of 2019 underscored that scarcity pricing was consistent with performance of the system.[3]

Key Observations for Summer 2019

- Early summer was mild, and August was very hot (September was also above normal).
- There were many days with tight conditions, and an Energy Emergency Alert (EEA) Level 1 was declared twice.
  - Emergency Response Service (ERS) deployments prevented the need for EEA2.
- Peak demand day saw higher Intermittent Renewable Resource (IRR) production.
  - As a result, it was not one of the highest-priced days, and there was no EEA.
- Tightest conditions frequently occurred earlier than time of peak demand.
- Resource performance continues to outpace historical patterns.
- Overall, the market outcomes supported reliability needs.
- Even with significant pricing events, there were no mass transitions.

Notably, high prices occurred at the right time, and were not socialized through capacity market charges spread over all load.

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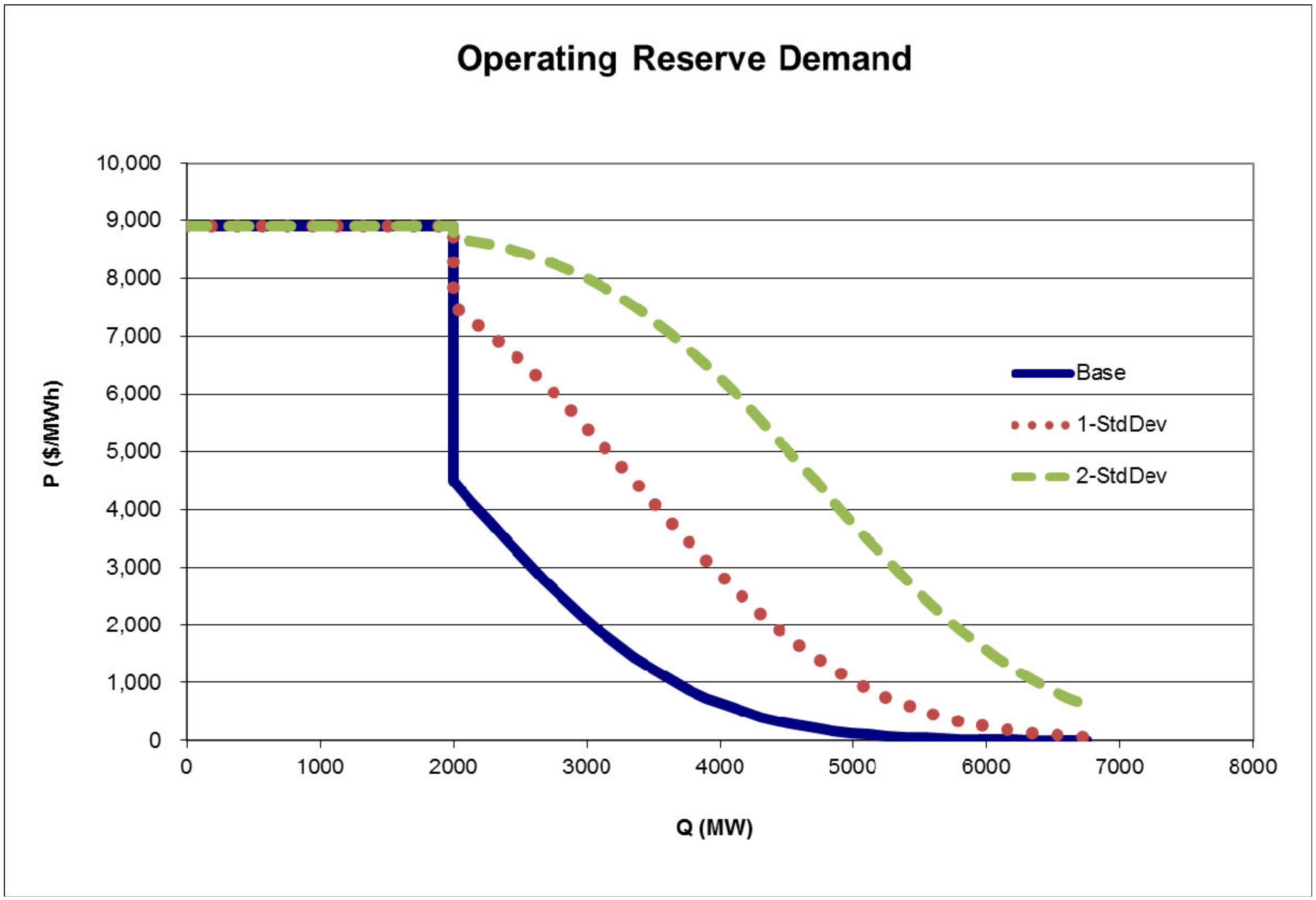
[3] Dan Woodfin and Carrie Bivens, "Summer 2019 Operational Review", ERCOT Board of Directors Meeting Presentation, October 8, 2019.

A conservative assumption addressed at reliability would be to increase the estimate of the loss of load probability. A shift of one standard deviation would have a material impact on the estimated scarcity prices. The choice would depend on the margin of safety beyond the economic base. Texas applied this approach in 2019 and 2020 by implementing 0.25 standard deviations shifts.



The February 2021 crisis in ERCOT provided a stunning example of a scarcity event. The scale is evident in the sustained high prices in $/MWh over four days.[4]

- A one-in-a-hundred-year (?) weather event covered Texas and large areas of the Midwest.
- Load increased while natural gas, coal, nuclear and renewable generators went offline.
- Natural gas pipelines and producing wells froze, reducing deliveries, including exports to Mexico.
- Electric power lines were down.
- The system operator took out-of-market actions to reduce demand and increase supply.
- Prices rose to $9000/MWh, for days not just hours.
- The system operator used the last of line of defense of rotating blackouts to prevent a total system collapse.
- A post-mortem will provide many lessons. One challenge will be to learn the right lessons.
- Was this a reasonably anticipated problem of a Black Swan that only looks obvious in retrospect?

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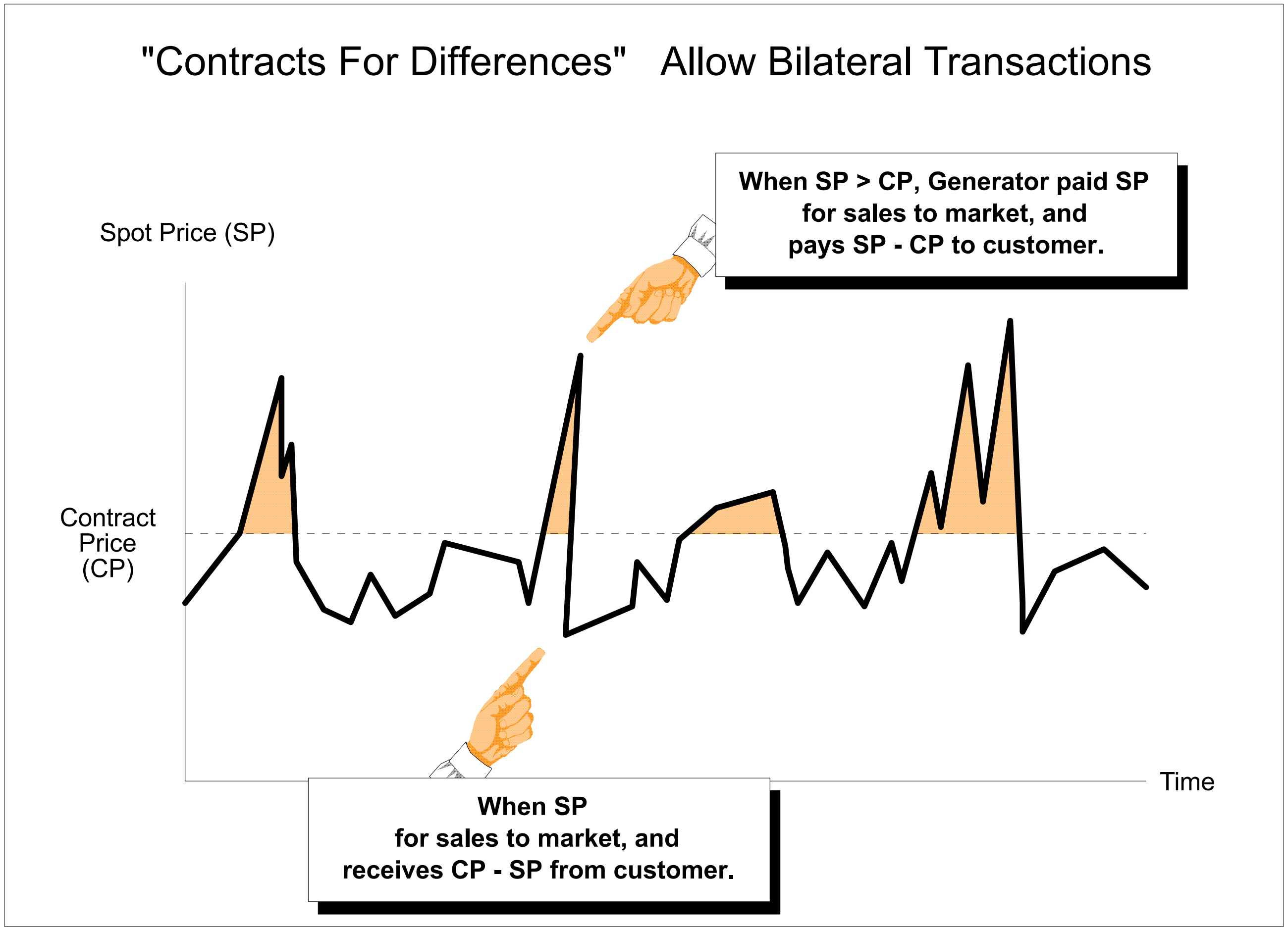
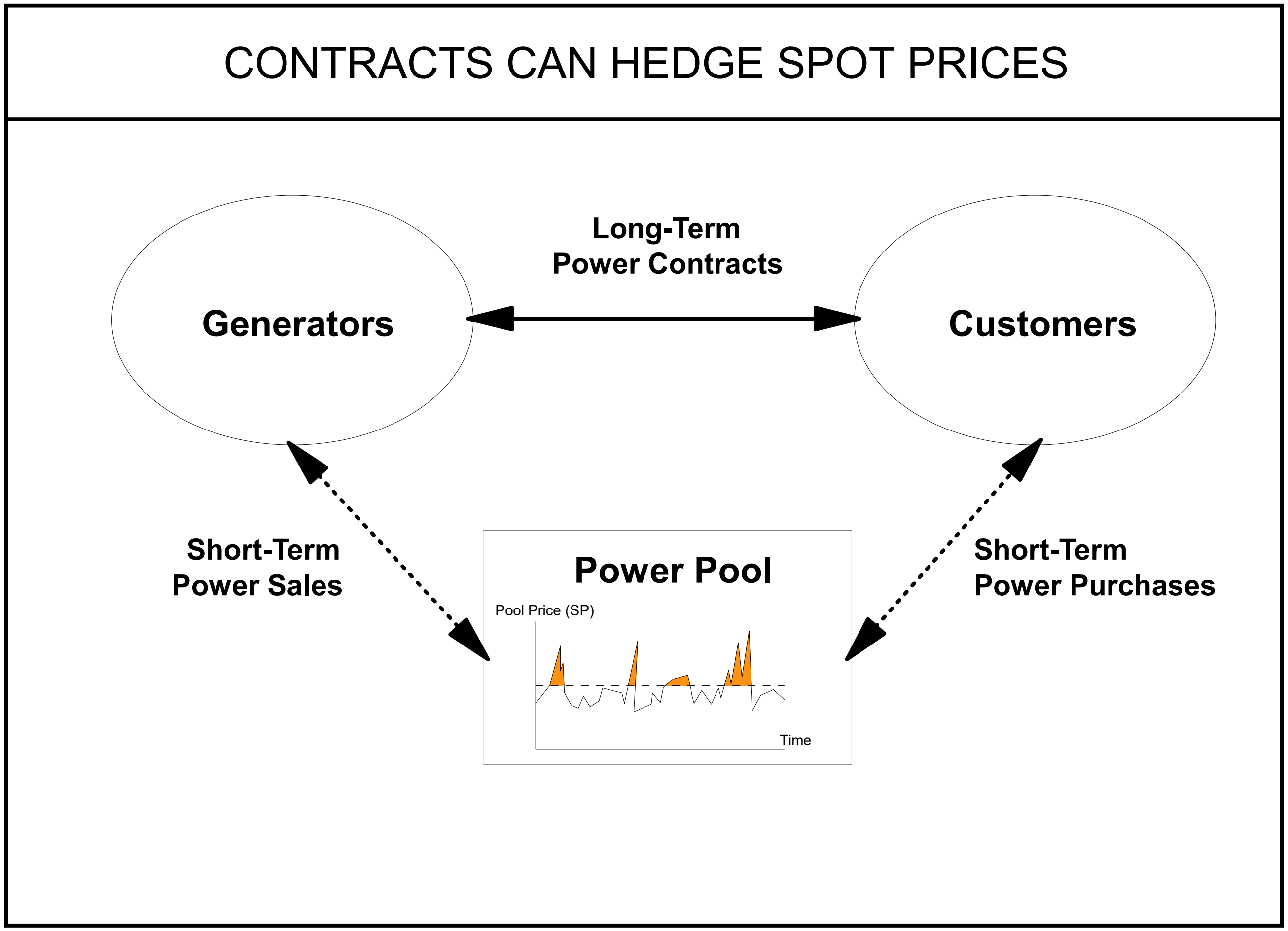
4 Source: LCG Consulting, Energyonline, http://www.energyonline.com/Data/GenericData.aspx?DataId=4&ERCOT___Real-time_Price

Appendix

The spot price in an electricity market can be highly volatile. A contract for differences offers a simple financial contract that replicates a fixed price contract. The seller sells to the pool. The buyer buys from the pool. The CFD provides a means to replicate a bilateral transaction.

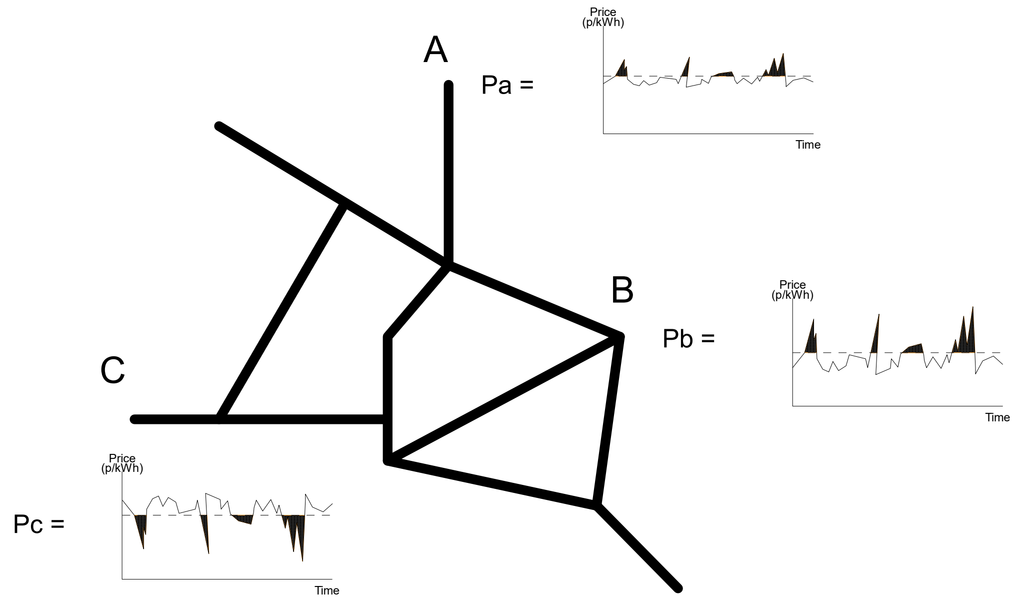


With the contracts for differences, the physical operation of the power pool becomes independent of the long-term contracts. Importantly, deliverability of the power does not depend on the contracts. The pool operates a spot market and produces spot prices for settlements.



For transmission between locations, the transmission opportunity cost is the difference in the locational prices. This difference of volatile prices will be even more volatile.

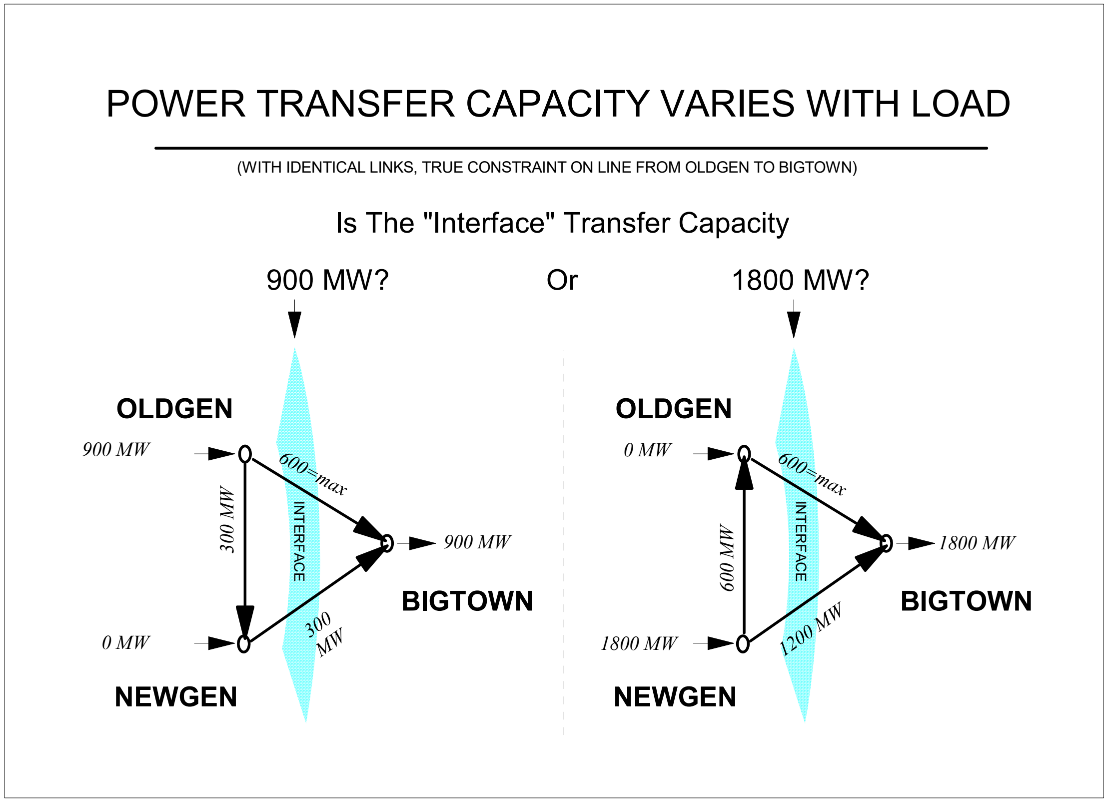
NEED "Hedges" FOR LOCATIONAL PRICING



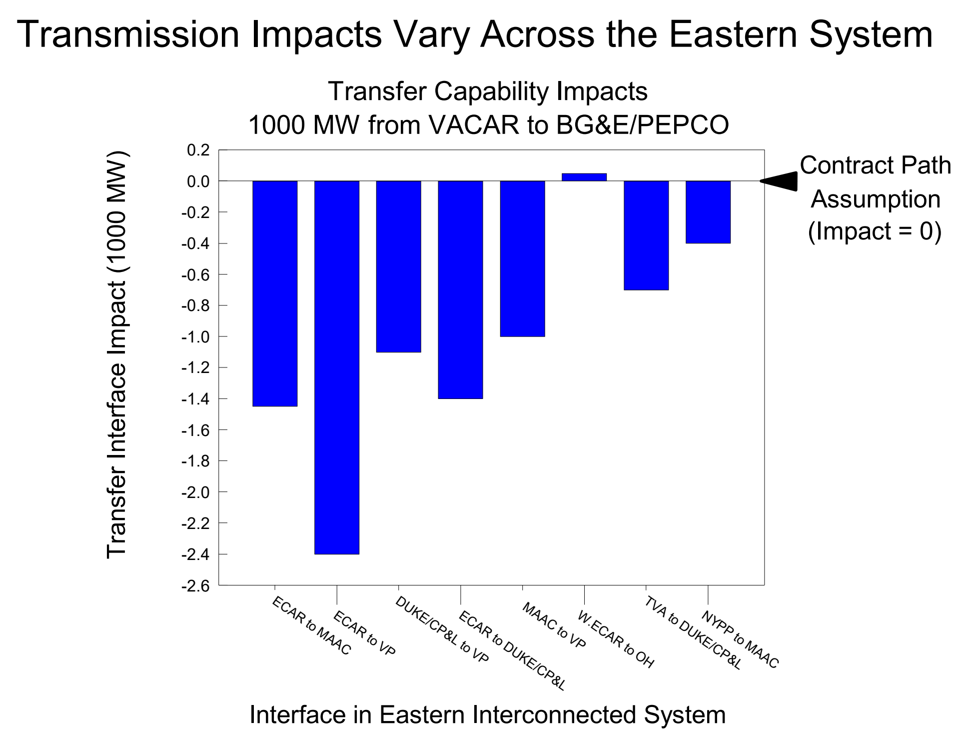
Price of "Transmission" from C to B = Pb - Pc = Volatile Price

Electric transmission network interactions can be large and important.

- Conventional definitions of network "Interface" transfer capacity depend on the assumed load conditions.
- Transfer capacity cannot be defined or guaranteed over any reasonable horizon.



There is a fatal flaw in the old "contract path" model of power moving between locations along a designated path. The network effects are strong. Power flows across one "interface" can have a dramatic effect on the capacity of other, distant interfaces.

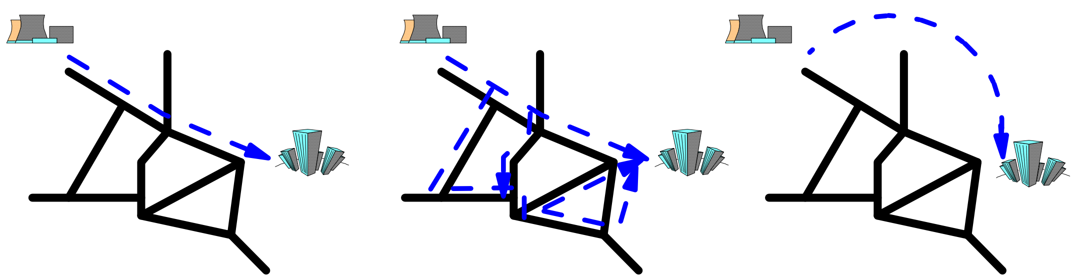


Source: VEM, Winter Operating Study, December 1993.

Defining and managing transmission usage is a principal challenge in electricity markets.

Transmission Capacity Definitions

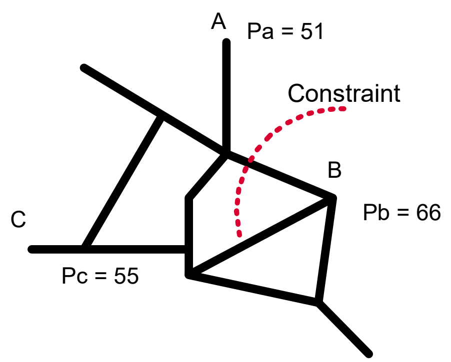
Contract Path ⟶ Flow-Based Paths ⟶ Point-to-Point



Contract Path Fiction	Parallel Flows	Flows Implicit
OASIS Schedules and TLR	Flowgate Rights FGRs	Financial Transmission Rights FTRs

A mechanism for hedging volatile transmission prices can be established by defining financial transmission rights to collect the congestion rents inherent in efficient, short-run spot prices. (Hogan, 1992)

NETWORK TRANSMISSION FINANCIAL RIGHTS



Price of "Transmission" from A to B = Pb - Pa = 15
Price of "Transmission" from C to A = Pa - Pc = -4

- DEFINE TRANSMISSION CONGESTION CONTRACTS BETWEEN LOCATIONS.
- FOR SIMPLICITY, TREAT LOSSES AS OPERATING COSTS.
- RECEIVE CONGESTION PAYMENTS FROM ACTUAL USERS; MAKE CONGESTION PAYMENTS TO HOLDERS OF CONGESTION CONTRACTS.
- TRANSMISSION CONGESTION CONTRACTS PROVIDE PROTECTION AGAINST CHANGING LOCATIONAL DIFFERENCES.

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