

Electricity Transmission in Deregulated Markets
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Testing the Effects of Inter-Regional Transfers of Real Energy on the Performance of Electricity Markets

by

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In collaboration with faculty at 12 other universities

PSERC was established by the National Science Foundation to facilitate “universities working with industry to find innovative solutions to challenges facing a restructured electric power industry and to educate the next generation of power industry engineers”.

The Conventional Explanation of How Ideal Markets for Electricity Should Work: I



• Actual Dispatch of Generators

- Use a Security Constrained Optimal Power Flow
- Minimize the cost of meeting load (using bids and offers) subject to explicit rules for reliability
 - Levels of reserves
 - Range of frequencies
- Reliability is treated as a shared property of the network (i.e. it is a Public Good)
- There is general agreement that a central decision maker (the System Operator) is needed to control real-time operations and to determine nodal prices for energy and ancillary services in the spot market
- There are no “seams” between adjoining power pools

The Conventional Explanation of How Ideal Markets for Electricity Should Work: II



- **Investment Decisions for Generation (and Load)**
 - Rely on decentralized decisions by market participants based on expected future spot prices and costs using forward markets
 - Generation adequacy is defined by the System Operator in terms of a specified reserve margin above the projected maximum load
 - Supplementary capacity payments may be needed to ensure that standards of generation adequacy are met (regulated price caps are too low and most loads do not pay the spot price in the USA)
 - The responsibility for meeting generation adequacy can be passed on to Load Serving Entities in a capacity market
 - Reliability is now treated implicitly as a private good, and the System Operator enforces the reserve margin but does not make any investment decisions for generation
 - Oren, 2004
 - Chao and Wilson, 2004
 - Joskow and Tirole, 2004

The Conventional Explanation of How Ideal Markets for Electricity Should Work: III



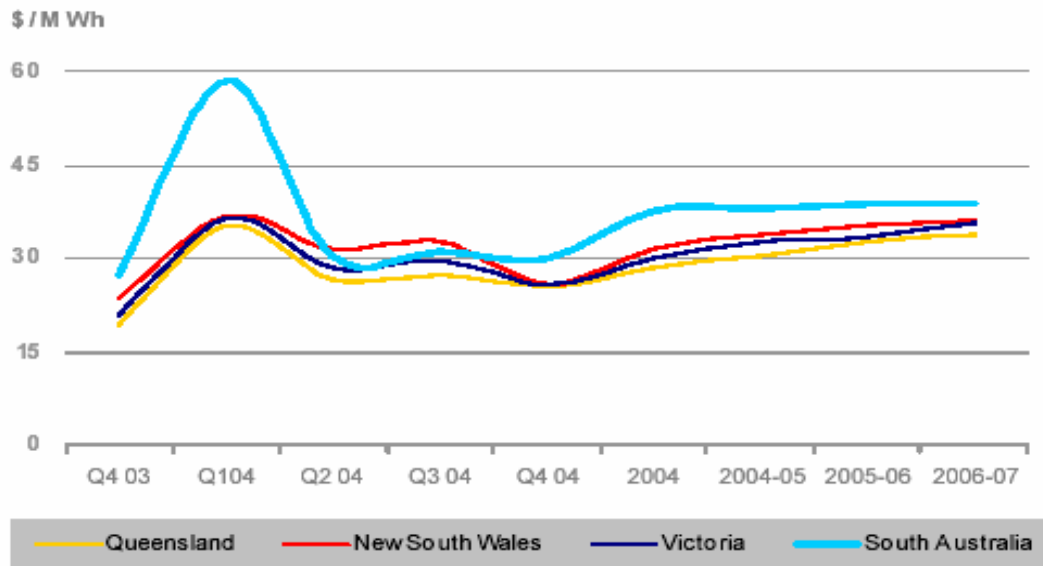
• Investment Decisions for Transmission

- The main purpose of transmission is to transfer real energy from low cost regions to high cost regions (i.e. the network can be treated as a pipeline)
- The appropriate payment for transmission owners is (Difference in nodal prices X Flow on line), and Financial Transmission Rights can be used for hedging
- Rely on decentralized decisions by market participants based on expected future differences in nodal prices and costs
- Transmission adequacy should be defined by the System Operator but, unlike generation adequacy, there is no simple rule for determining transmission adequacy
- Some mixture of centralized and decentralized decisions for investment in transmission is needed, but it is difficult to assign investment responsibilities in a tractable way
 - Hogan, 2003
 - Outhred, 2004

An Example of a Pretty Good Market: Australia I



1. Spot and forward prices in different regions are converging
2. Price differences due to congestion are getting smaller
3. Average prices are relatively low (around \$35A/MWh)



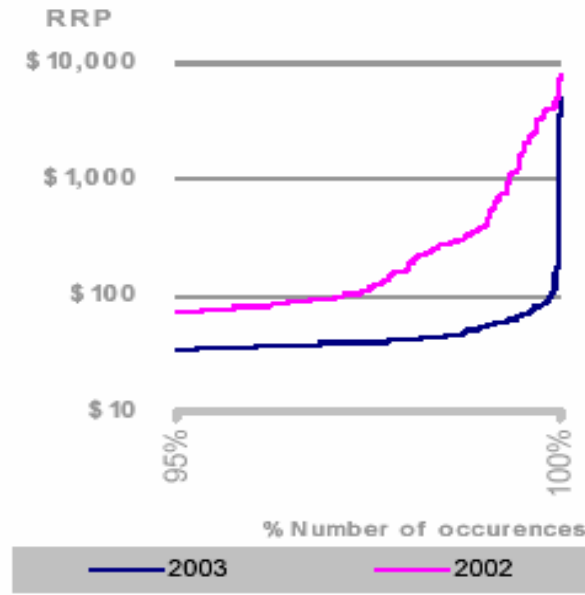
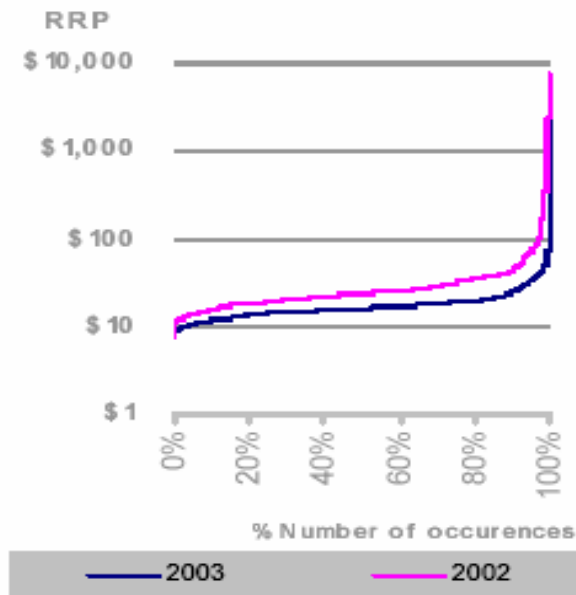
4 ANNUAL AVERAGE
FLAT CONTRACT
PRICE

Source: NECA Statistical Digest, Jan. 2004

An Example of a Pretty Good Market: Australia II



1. High spot prices do occur (price cap is \$10,000A/MWh), but average prices were lower in 2003 than in 2002
2. Price duration curve is relatively consistent with the average total cost for generators with low capacity factors



25 QUEENSLAND
CUMULATIVE SPOT
PRICE DURATION

Source: NECA Statistical Digest, Jan. 2004

Long-Term Reliability Assessment

North American Electric Reliability Council (NERC)

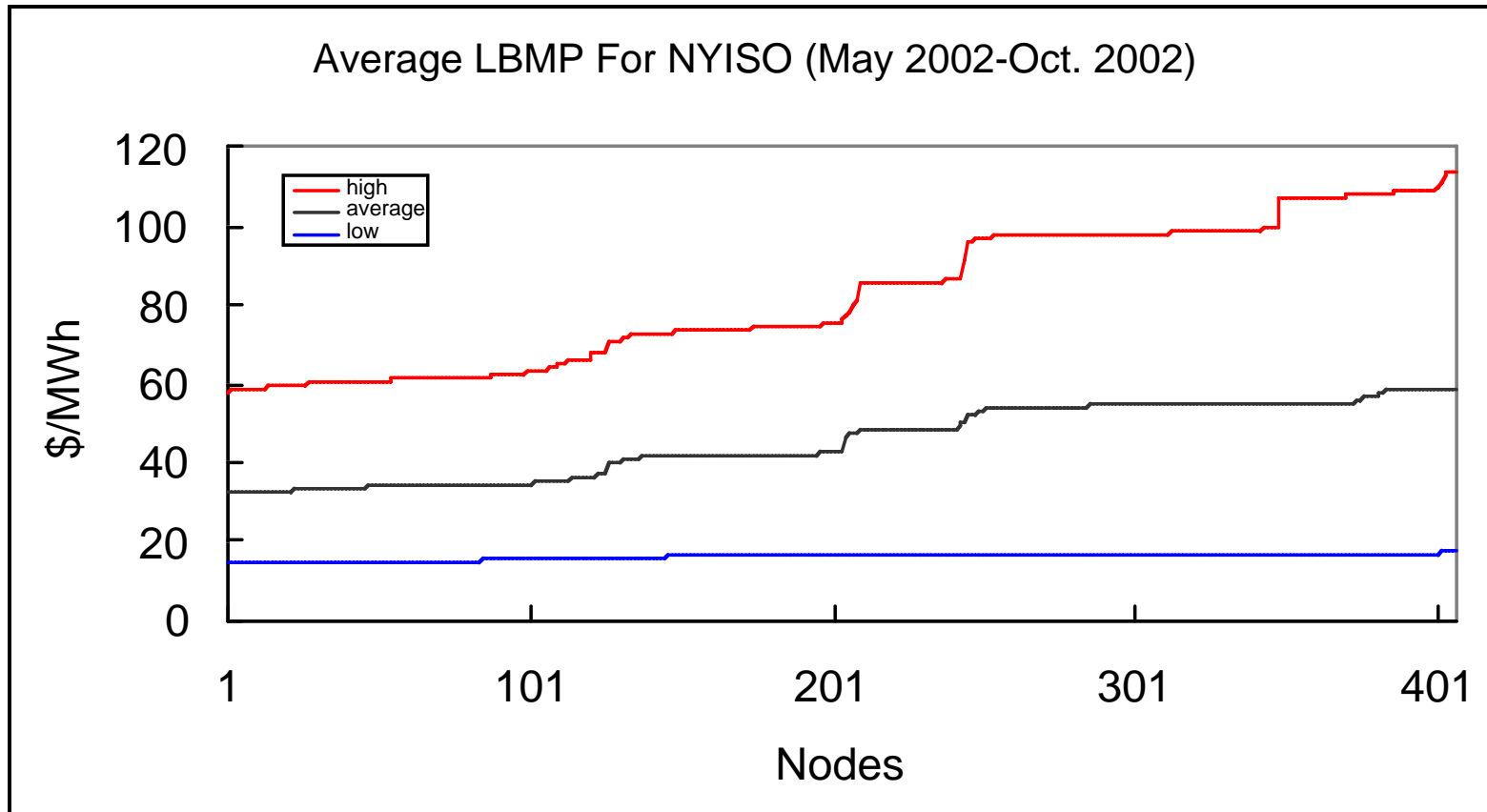
(September 2004, p. 34)



Over the past decade, the increased demands placed on the transmission system in response to industry restructuring and market-related needs are causing the grid to be operated closer to its reliability limits more of the time.

The demand for electricity continued to grow in the 1980s and 1990s, but transmission additions have not kept pace. The uncertainty associated with transmission financing and cost recovery and the impediments to siting and building new transmission facilities have resulted in a general slow-down in construction of new transmission.....The result is increased loading on existing transmission systems and tighter transmission operating margins.

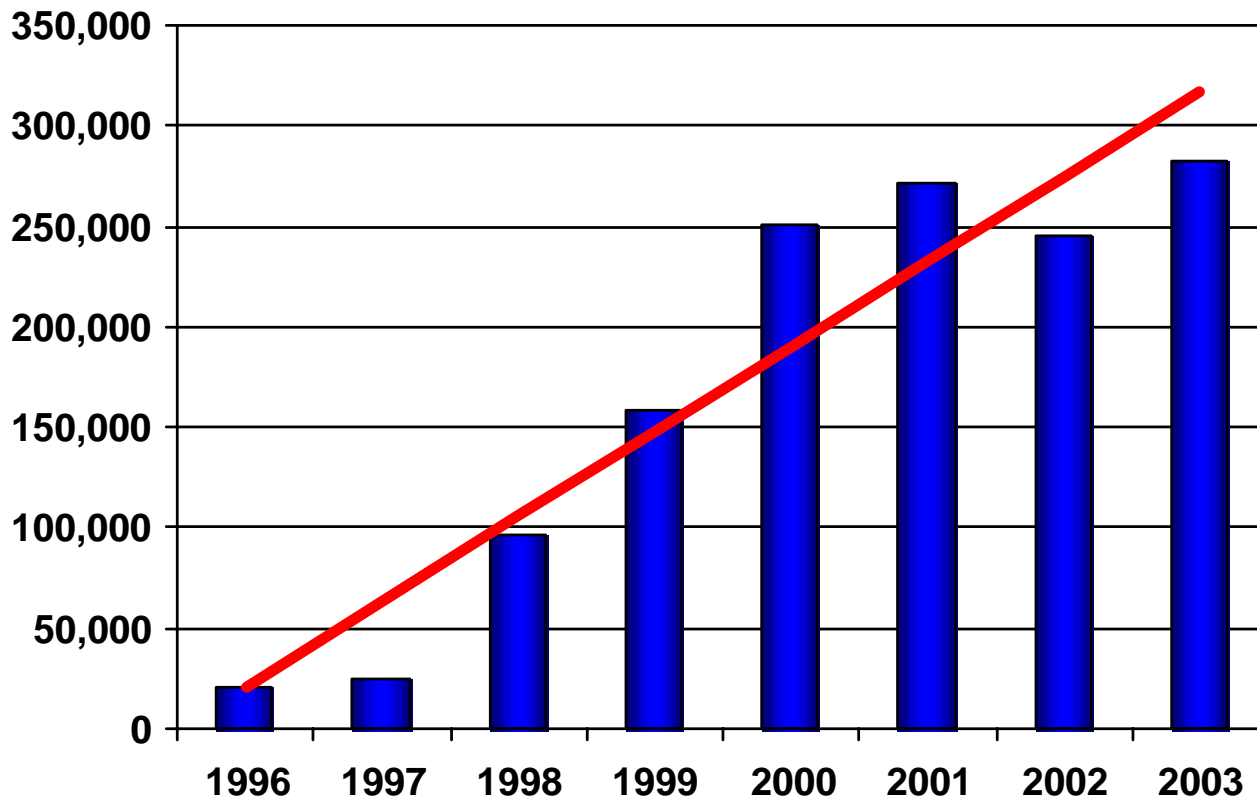
Ranked Location Based Marginal Prices (LBMP) in New York State



Average Nodal Prices are ranked (correspond roughly to W --> SE locations)

High: > 90th percentile of load (same ranking)

Low: < 10th percentile of load (same ranking)



- Transactions at TVA have grown over 1,000% since 1996
- Many occurred during times of tight system resources

Why Use PowerWeb to Test Markets?



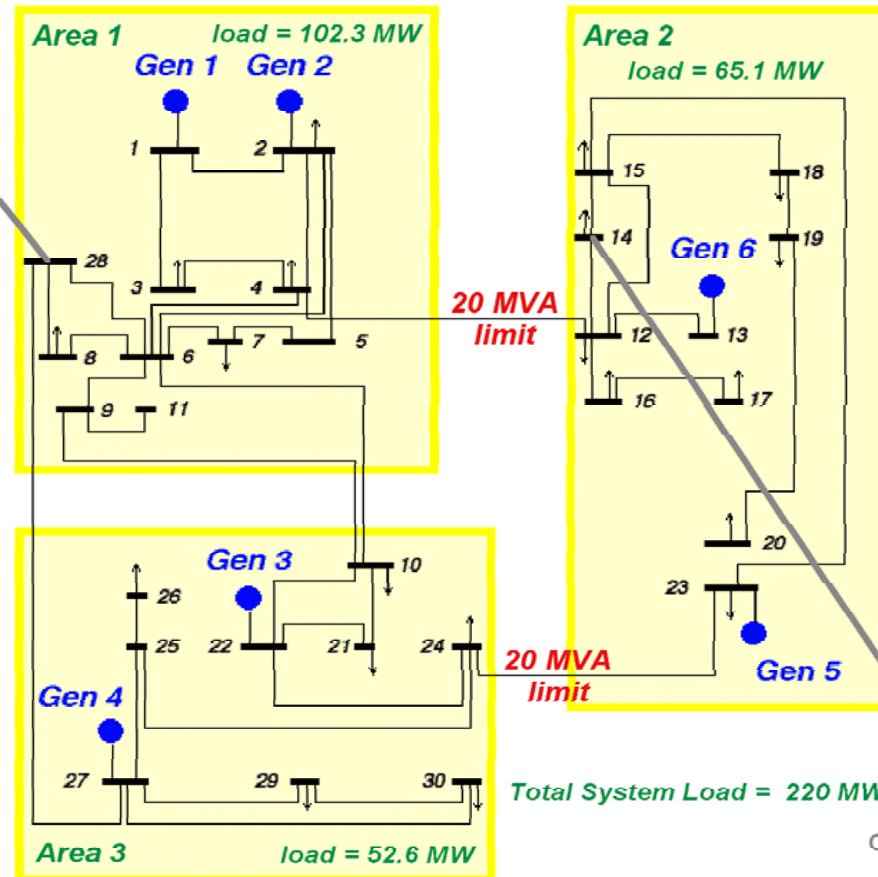
- Market structures for electricity auctions are **too complicated** to derive analytical results.
- PowerWeb tests are **inexpensive** compared to experimenting directly on the public.
- **Paying participants** in market tests on the basis of their performance duplicates market behavior effectively.
- The effects of **specific market characteristics** can be isolated and tested.
- PowerWeb supports a **full AC network**, so that the market implications of congestion and ancillary services -- as well as real energy -- can be studied.
- Our motto: **TEST NOW or PAY LATER**

PowerWeb Network

Six Generators (Firms) and 30 Buses



Connection to NW



The Screen Used by a Firm to Submit Offers into a Central Auction





Name: [my@e.mail] Test User [Logout](#)

Session: [2] Example Session

Representing: [8] Seller 1

Period

1

SYSTEM DATA	
Forecasted Load (MW)	519.0
Installed Capacity (MW)	600.0
Price Cap (\$/MW)	\$100.00

GENERATOR DATA	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5
Min Generation (MW)	0.0	0.0	0.0	0.0	0.0
Max Capacity (MW)	50.0	20.0	10.0	10.0	10.0
Variable Cost (\$/MW)	\$20.00	\$40.00	\$48.00	\$50.00	\$52.00
Standby Cost (\$/MW)	\$5.00	\$5.00	\$5.00	\$5.00	\$5.00
Fixed Cost (\$)	\$600.00	\$300.00	\$100.00	\$100.00	\$100.00
MY OFFERS	Gen 1	Gen 2	Gen 3	Gen 4	Gen 5
Shutdown?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>
Energy Offer (\$/MW)	\$ 20	\$ 40	\$ 50	\$ 60	\$
<input type="button" value="Submit Offer"/>					
Standby Costs (\$)	\$ 250	\$ 100	\$ 50	\$ 50	\$ 0

Testing the Effects of Inter-Regional Transfers of Energy



Six Firms (graduate students in AEM and ECE)

Three Sessions (replications)

Three Markets

1. No transfers.

(periods 1-15)

2. A 40 MW transfer from bus 28 to bus 14 (NW to SE).

(periods 16-45)

3. A 40 MW transfer from bus 14 to bus 28 (SE to NW).

(periods 46-75)

General Characteristics

System load varies from period to period.

Nodal Prices are determined by an Optimal Power Flow (OPF).

Expensive imports are available if there is excessive withholding.

Offers and Dispatch by Firm

High Offers <---> **Low Offers**

1-15 NO transfers, 16-45 W --> E, 46-75 E --> W



QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Price Contours (high -- low)

NO TRANSFERS, COMPETITIVE OFFERS

1-15 NO transfers, 16-45 W --> E, 46-75 E --> W



QuickTime™ and a
PNG decompressor
are needed to see this picture.

Price Contours (high -- low)

ACTUAL TRANSFERS, COMPETITIVE OFFERS

1-15 NO transfers, 16-45 W --> E, 46-75 E --> W



QuickTime™ and a
PNG decompressor
are needed to see this picture.

Price Contours (**high** -- **low**)

ACTUAL TRANSFERS, ACTUAL OFFERS

16-45 W --> E, 46-75 E --> W



QuickTime™ and a
PNG decompressor
are needed to see this picture.

Flow Difference (**COMPETITIVE OFFERS**)

ACTUAL TRANSFERS - NO TRANSFERS

16-45 W --> E, 46-75 E --> W



QuickTime™ and a
PNG decompressor
are needed to see this picture.

Flow Difference (ACTUAL TRANSFERS)

ACTUAL OFFERS - COMPETITIVE OFFERS

1-15 NO transfers, 16-45 W --> E, 46-75 E --> W



QuickTime™ and a
PNG decompressor
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Analysis of Variance

Test Results for Inter-Regional Transfers



Dependent Variable: **EARNINGS BY FIRM** (15 periods)

Source	Sum of Squares	%	Df	Mean Square	F stat.
Market	2,088,953.00	7.73	2	1,044,476.50	10.426
Firm	2,188,433.00	8.10	5	437,686.60	4.369
Session	6,288,920.00	23.28	2	3,144,460.00	31.387
MarketXFirm	11,012,835.00	40.77	10	1,101,283.50	10.993
MarketXSession	789,204.00	2.92	4	197,301.00	1.969
FirmXSession	2,637,876.00	9.77	10	263,787.60	2.633
Error	2,003,690.00	7.42	20	100,184.50	
Total	27,009,911.00	100.00	53		

Conclusion # 1

Wheeling Affects BOTH the Engineering and Economic Characteristics of the Market



Wheeling real energy through a network may increase flows sufficiently to reach voltage and thermal limits on transmission lines. This type of congestion increases market power for some generators (and could be a major impediment for others). Congested systems are easier for suppliers to exploit and raise prices above the competitive level because the market is spatially fragmented.

Even though the quantity of real energy flowing through the network stayed the same for a number of periods in the experiments, the flows on individual lines were quite erratic. Identifying accounting pathways for physical bilateral contracts defies the laws of physics and is highly misleading in a deregulated market.

The Basic Scheduling Algorithm for the Co-optimization of Energy and Reserves



- **Objective**

- Minimize the total expected cost (operating energy cost plus the spinning reserve cost) for N generators over the predefined base case and K credible contingencies.

$$S = \sum_{k=0}^K p_k \sum_{i=1}^N [C_{Pi}(G_{ki}) + C_{Ri}(R_{ki})] \quad \sum_{k=0}^K p_k = 1$$

- **Subject to network and system constraints**

- Generation capacity limits
- Voltage limits
- Line flow limits
- Ramping limits

Conclusion # 2

Maintaining Reliability is Expensive



Maintaining acceptable levels of reliability requires having some expensive generators available to meet load and cover relatively rare contingencies (i.e. they are dispatched out-of-merit order at the physical minimum level).

Although maintaining reliability is a socially efficient decision, the capital cost/MWh generated in a contingency can be extremely high, and typically, price caps in the USA are too low to cover the long-run marginal costs of the expensive generators needed to ensure that the supply system is reliable.

Regulators place much too much emphasis on short-run marginal costs to judge the performance of deregulated markets. A few price spikes are perfectly acceptable if the overall average price is low.

Conclusion # 3

Reliability is Always a Public Good



It is inappropriate to use a specified reserve margin as a proxy for reliability in a deregulated market. Although generation adequacy is necessary for reliability, it is not sufficient. The primary role of transmission in an AC network is to maintain the reliability of supply. Decisions about transmission adequacy cannot be decentralized in a market because reliability is a public good.

The pipeline analogy for paying transmission owners is appropriate for a DC intertie but not for an AC network. The AC transmission system should be fully regulated using performance-based rates of return that penalize unscheduled outages. Revenues collected by an ISO from nodal price differences should be pooled and used to pay all transmission owners (and the owners of expensive generators needed for reliability).

Final Conclusion



- System adequacy is much too important to rely on regulators and/or market forces to determine the “correct” prices needed to provide sufficient incentives for investors. Furthermore, the standard reliability criterion used in market solutions (e.g. a fixed ratio between reserves and load) is a crude measurement that does not reflect the actual supply conditions in a deregulated market.
- The modifications to prices proposed by economists are “*ad hoc corrections introduced as needed to save appearances, like the epicycles of Ptolemaic astronomy*” (Daly and Cobb, p. 37, *The Common Good*, Beacon Press, 1989)