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MISSOURI PUBLIC SERVICE COMMISSION

CASE NO.: EO-2011-0390

DIRECT TESTIMONY

OF

DR. C.K. WOO

ON BEHALF OF

KCP&L GREATER MISSOURI OPERATIONS COMPANY

Kansas City, Missouri
February 2012

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DIRECT TESTIMONY

OF

DR. C.K. WOO

Case No. EO-2011-0390

Q: Please state your name, business affiliation and address.

A: My name is C.K. Woo. I am a senior partner of Energy and Environmental Economics, Inc. ("E3"), a consulting firm located at 101 Montgomery Street, Suite 1600, San Francisco, CA 94104, USA.

Q: Please describe your qualifications and experience.

A: I specialize in electricity economics, applied microeconomics, and applied finance. With 30 years of experience in the electricity industry, I have testified and prepared expert testimony for use in regulatory and legal proceedings in California, British Columbia and Ontario. I have also filed declaration for and testified in arbitration in connection to electricity contract disputes.

As indicated in my résumé (Schedule CKW-1), I have published over 100 refereed articles on electricity economics, applied microeconomics, and applied finance. Recognized by WHO'S WHO IN AMERICA, WHO'S WHO IN FINANCE AND BUSINESS, and WHO'S WHO IN SCIENCE AND ENGINEERING, I am (a) an associate editor of ENERGY and their guest editor of a special issue on electricity market reform and deregulation and a special issue on demand response resources; (b) a member of the editorial board of THE ENERGY JOURNAL and their guest editor for a special issue on electricity reliability; (c) a guest editor for a special issue of ENERGY POLICY on renewable energy; (d) an affiliate with Hong Kong Energy Studies Centre, Baptist University of Hong Kong; and (e) an adjunct professor of economics at the City University of Hong Kong.

Prior to joining E3, I was an associate professor at City University of Hong Kong, a senior associate at Analysis Group, a rate economist at Pacific Gas and Electric Company, and an econometrician at Sacramento Municipal Utilities District. I have a Ph.D. in Economics from University of California, Davis.

Q: Please detail your experience in electricity procurement and risk management.

A: I have provided advice to utilities and large electricity users, whose identities I cannot reveal due to non-disclosure agreements. My advice is based on my research exemplified by the following refereed publications:

- C.K. Woo, I. Horowitz and K. Hoang, *Cross Hedging and Forward-Contract Pricing of Electricity*, 23 ENERGY ECONOMICS 1-15 (2001).
- C.K. Woo, I. Horowitz and K. Hoang, *Cross Hedging and Value at Risk: Wholesale Electricity Forward Contracts*, 8 ADVANCES IN INVESTMENT ANALYSIS AND PORTFOLIO MANAGEMENT 283-301 (2001).
- C.K. Woo, A. Olson and R. Orans, *Benchmarking the Price Reasonableness of an Electricity Tolling Agreement*, 17(5) ELECTRICITY JOURNAL 65-75 (2004).
- C.K. Woo, D. Lloyd, M. Borden, R. Warrington and C. Baskette, *A Robust Internet-Based Auction to Procure Electricity Forwards*, 29 ENERGY 1-11 (2004).
- C.K. Woo, I. Horowitz, B. Horii and R. Karimov, *The Efficient Frontier for Spot and Forward Purchases: An Application to Electricity*, 55 JOURNAL OF THE OPERATIONAL RESEARCH SOCIETY 1130-1136 (2004).

- D. Lloyd, C.K. Woo, M. Borden, R. Warrington and C. Baskette, *Competitive Procurement and Internet-based Auction: Electricity Capacity Option*, 17(4) ELECTRICITY JOURNAL 74-78 (2004).
- C.K. Woo, R. Karimov and I. Horowitz, *Managing Electricity Procurement Cost and Risk by a Local Distribution Company*, 32 ENERGY POLICY 635-645 (2004).
- C.K. Woo, D. Lloyd and W. Clayton, *Did a Local Distribution Company Procure Prudently during the California Electricity Crisis*? 34 ENERGY POLICY 2552-2565 (2006).
- C.K. Woo, A. Olson and I. Horowitz, *Market Efficiency, Cross Hedging and Price Forecasts: California's Natural-Gas Markets*, 31 ENERGY 1290-1304 (2006).
- C.K. Woo, I. Horowitz, A. Olson, B. Horii and C. Baskette, *Efficient Frontiers for Electricity Procurement by an LDC with Multiple Purchase Options*, 34 OMEGA 70-80 (2006).
- C.K. Woo, I. Horowitz, N. Toyama, A. Olson, A. Lai and R. Wan, *Fundamental Drivers of Electricity Prices in the Pacific Northwest*, 5 ADVANCES IN QUANTITATIVE ANALYSIS OF FINANCE AND ACCOUNTING 299-323 (2007).
- J. Moore, C.K. Woo, B. Horii, S. Price and A. Olson, *Estimating the Option Value of a Non-firm Electricity Tariff*, 35 ENERGY 1609-1614 (2010).
- C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011).

- A. DeBenedictis, D. Miller, J. Moore, A. Olson and C.K. Woo, *How Big is the Risk Premium in an Electricity Forward Price? Evidence from the Pacific Northwest*, 24(3) ELECTRICITY JOURNAL 72-76. (2011).
- C.K. Woo, I. Horowitz, J. Moore and A. Pacheco, *The Impact of Wind Generation on the Electricity Spot-Market Price Level and Variance: The Texas Experience*, 39 ENERGY POLICY 3939-3944 (2011).
- C.K. Woo, I. Horowitz, B. Horii, R. Orans and J. Zarnikau, *Blowing in the Wind: Vanishing Payoffs of a Tolling Agreement for Natural-Gas-Fired Generation of Electricity in Texas*, 33(1) THE ENERGY JOURNAL 207-229 (2012).

Q: Have you previously testified in a proceeding at the Missouri Public Service Commission ("MPSC")?

A: No.

Q: What is the purpose of your Direct Testimony?

A: I have been retained by Great Plains Energy Services Incorporated, an affiliate of KCP&L Greater Missouri Operations Company ("GMO") to: (1) explain cross hedging in an electric utility's risk management of procurement costs; and (2) respond to certain statements made in (a) STAFF'S THIRD PRUDENCE REVIEW REPORT AND RECOMMENDATION ON KCP&L GREATER MISSOURI OPERATIONS COMPANY'S FAC dated November 29, 2011 ("Staff Report A" hereafter), and (b) PRUDENCE REVIEW OF COSTS RELATED TO THE FUEL ADJUSTMENT CLAUSE FOR THE ELECTRIC OPERATIONS OF KCP&L GREATER MISSOURI OPERATIONS COMPANY dated November 28, 2011 ("Staff Report B" hereafter) (collectively, "Staff Reports").

Q: What are your findings?

A: My findings are as follows:

- An electric utility faces procurement cost risks that may be mitigated via generation ownership, electricity forward contracts, tolling agreements, and capacity options. However, the utility continues to face electricity and natural gas spot price risks.
- The prudence of the utility's risk management activities should not be based the utility's *ex post* (after-the-fact) loss observed with 20/20 hindsight.
- Cross hedging via natural gas futures can be effective in reducing the utility's natural gas spot price risk.
- Cross hedging via natural gas futures can be effective in reducing the utility's electricity spot price risk.
- Cross hedging can result in an *ex post* loss, even if the utility's *ex ante* (before-the-fact) hedging decision is prudently made to reduce the spot price risks.
- The MPSC Staff's statements are misguided. My findings do not support the MPSC Staff's finding that the use of natural gas futures to cross hedge the electricity spot price is imprudent, "akin to placing a bet in the stock market in hopes of generating enough cash to pay for a future variable expense." (Staff Report B, p.10).

Q: How is your testimony organized?

A: Section I discusses an electric utility's management of electricity procurement cost risk, thereby providing a contextual background for cross hedging. Section II explains cross hedging. Section III describes how to use natural gas futures to cross hedge the natural gas spot price. Section IV describes how to use natural gas futures to cross hedge the electricity spot price. Section V responds to certain statements made in the Staff Reports regarding cross hedging.

I. <u>MANAGEMENT OF ELECTRICITY PROCUREMENT COST RISKS</u>

Q: What is a commonly used measurement of risk?

A: It is the standard deviation of a financial variable (e.g., the daily return of the S&P 500 Index or the daily price of a commodity).[1]

Q: Please describe electricity procurement cost risk.

A: Consider a hypothetical electric utility that procures from the wholesale electricity spot market to meet its retail load obligation. The utility faces (a) a volume risk because its retail load is time-dependent and fluctuates with random weather and economic conditions; and (b) an electricity spot price risk because electricity spot prices are highly volatile with occasional sharp spikes.[2]

The utility's market-based procurement cost is its retail load times the electricity spot price. Empirical evidence suggests that load and electricity spot price levels are positively correlated, and the utility likely sees high loads on high-price days.[3] Thus, the utility's procurement cost risk is larger than what the volume risk or electricity spot price risk would individually suggest.[4]

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[1] E.J. Elton and M. J. Gruber, MODERN PORTFOLIO THEORY AND INVESTMENT ANALYSIS (John Wiley & Sons, 1995) at 46.

[2] For a discussion on and references for electricity spot price behavior, see C.K. Woo, I. Horowitz, J. Moore and A. Pacheco, *The Impact of Wind Generation on the Electricity Spot-Market Price Level and Variance: The Texas Experience*, 39 ENERGY POLICY 3939-3944 (2011); C.K. Woo, I. Horowitz, N. Toyama, A. Olson, A. Lai, and R. Wan, *Fundamental Drivers of Electricity Prices in the Pacific Northwest*, 5 ADVANCES IN QUANTITATIVE ANALYSIS OF FINANCE AND ACCOUNTING 299-323 (2007).

[3] C.K. Woo, I. Horowitz, J. Moore and A. Pacheco, *The Impact of Wind Generation on the Electricity Spot-Market Price Level and Variance: The Texas Experience*, 39 ENERGY POLICY 3939-3944 (2011).

[4] C.K. Woo, R. Karimov and I. Horowitz, *Managing Electricity Procurement Cost and Risk by a Local Distribution Company*, 32 ENERGY POLICY 635-645 (2004).

Q: Should the utility manage its procurement cost risk?

A: Yes. By managing its cost risk, the utility can limit the potential bill increases to its customers.[5]

Q: What if the utility does not manage its procurement cost risk?

A: The utility may incur very large procurement costs, as dramatically demonstrated by the California energy crisis in 2000-2001, with adverse financial consequences for the utility and its customers.[6]

Q: Is mitigating cost exposure the same as minimizing expected cost?

A: No. Mitigating cost exposure requires hedging against volume and spot price risks, which likely increases the utility's expected cost.[7] In other words, it is unlikely that the utility can reduce its cost risk exposure and at the same time lower its expected cost.

Q: What are the common alternatives available for managing procurement cost risk?

A: Besides generation ownership, they are forward contracts, tolling agreements, and capacity options.[8]

Q: Does generation ownership eliminate the utility's electricity and natural gas spot price risks?

A: No. Consider the ownership of a natural gas turbine. The utility can use the turbine to produce electricity or procure the same amount from the electricity spot market. The per MWh cost resulting from the utility's least-cost decision is the lesser of (a) the electricity

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[5] C.K. Woo, R. Karimov and I. Horowitz, *Managing Electricity Procurement Cost and Risk by a Local Distribution Company*, 32 ENERGY POLICY 635-645 (2004).
[6] C.K. Woo, *What Went Wrong in California's Electricity Market*? 26 ENERGY 747-758 (2001).
[7] C.K. Woo, R. Karimov and I. Horowitz, *Managing Electricity Procurement Cost and Risk by a Local Distribution Company*, 32 ENERGY POLICY 635-645 (2004); C.K. Woo, I. Horowitz, B. Horii and R. Karimov, *The Efficient Frontier for Spot and Forward Purchases: An Application to Electricity*, 55 JOURNAL OF THE OPERATIONAL RESEARCH SOCIETY 1130-1136 (2004); C.K. Woo, I. Horowitz, A. Olson, B. Horii and C. Baskette, *Efficient Frontiers for Electricity Procurement by An LDC with Multiple Purchase Options*, 34 OMEGA 70–80 (2006).
[8] S. Deng and S.S. Oren, *Electricity Derivatives and Risk Management*, 31 ENERGY 940–953 (2006).

spot price, or (b) the turbine's per MWh fuel cost, which is turbine's heat rate times the natural gas spot price. Since this per MWh cost varies with both spot prices, generation ownership does not eliminate spot price risks.

Q: Please describe an electricity forward contract.

A: An electricity forward contract obligates the seller to sell and the buyer to buy a contracted amount of electricity at a fixed price and specified future time. After signing a forward contract, the utility eliminates its exposure to the electricity spot price risk for the contracted amount of electricity.[9] In exchange for providing price certainty, the forward contract seller charges a risk premium above the expected electricity spot price in the forward price.[10]

Q: Does a forward contract eliminate the utility's electricity spot price risk?

A: No, because the forward contract can only provide price certainty for the contracted amount of electricity. If the contracted amount differs from the utility's retail sale requirement, the utility may need to transact in the wholesale market, thus facing electricity spot price risk.[11]

Q: What if the average electricity spot price during the forward contract's delivery period stays below the forward price?

A: The utility would incur an *ex post* loss equal to the contracted amount times the difference between the forward price and the average spot price. However, this does not mean the utility's *ex ante* decision of buying the forward contract is imprudent because

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[9] C.K. Woo, I. Horowitz and K. Hoang, *Cross Hedging and Forward-Contract Pricing of Electricity*, 23 Energy Economics 1-15 (2001).

[10] A. DeBenedictis, D. Miller, J. Moore, A. Olson and C.K. Woo, *How Big is the Risk Premium in an Electricity Forward Price? Evidence from the Pacific Northwest*, 24(3) ELECTRICITY JOURNAL 72-76. (2011).

[11] C.K. Woo, R. Karimov and I. Horowitz, *Managing Electricity Procurement Cost and Risk by a Local Distribution Company*, 32 ENERGY POLICY 635-645 (2004).

the decision's prudence should be based on the contract's usefulness in reducing the utility's procurement risk,[12] not the *ex post* loss observed with 20/20 hindsight.

Q: Please describe a tolling agreement.

A: "A tolling agreement gives the [utility] the right, but not the obligation, to dispatch a specified generation unit during the term of the agreement. The [utility] procures the fuel, typically natural gas, and absorbs the fuel price risk."[13] After making a capacity payment to the unit's owner, the utility economically dispatches the unit when the spot market price exceeds the unit's per-MWh variable cost, thereby reducing its exposure to electricity spot price spikes.[14]

Q: Does a tolling agreement eliminate the utility's electricity and natural gas spot price risks?

A: No. The electricity procured via a tolling agreement has a per MWh cost that is the lesser of (a) the electricity spot price, or (b) the agreement's per MWh fuel cost, which is the natural gas spot price times the heat rate specified in the tolling agreement.[15] This per MWh cost fluctuates with electricity and natural gas spot prices, implying that the electric utility faces both spot price risks.

Q: What if the electricity spot prices during the agreement's contract period stay below the per MWh fuel costs in (b) above?

A: The agreement would be unused and expire worthless. Thus, the utility would incur an *ex post* loss equal to its capacity payment for the agreement. However, this does not

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[12] C.K. Woo, I. Horowitz, B. Horii and R. Karimov, *The Efficient Frontier for Spot and Forward Purchases: An Application to Electricity*, 55 JOURNAL OF THE OPERATIONAL RESEARCH SOCIETY 1130-1136 (2004).

[13] C.K. Woo, A. Olson and R. Orans, *Benchmarking the Price Reasonableness of an Electricity Tolling Agreement*, 17(5) ELECTRICITY JOURNAL 65-75 (2004) at 66.

[14] C.K. Woo, I. Horowitz, A. Olson, B. Horii and C. Baskette, *Efficient Frontiers for Electricity Procurement by An LDC with Multiple Purchase Options*, 34 OMEGA 70–80 (2006).

mean the utility's *ex ante* decision of buying the option is imprudent because the decision's prudence should be based on the agreement's usefulness in reducing the utility's procurement risk,[16] not the *ex post* loss observed with 20/20 hindsight.

Q: Please describe a capacity option.

A: A capacity (call) option gives the buyer the right, but not the obligation, to buy electricity at a preset strike price (e.g., $150/MWh) with specific conditions (e.g., 10 MW for a 3-month period, 8 hours per day minimum per exercised call, and 480 MWh per month maximum energy take).[17] Thus, the strike price is the maximum price that the utility would pay for electricity from exercising the option.

Q: What if the electricity spot price during the option's contract period stays below the strike price?

A: The option would be unused and expire worthless. Thus, the utility would incur an *ex post* loss equal to its payment for the capacity option. However, this does not mean the utility's *ex ante* decision of buying the option is imprudent because the decision's prudence should be based on the option's capacity payment and expected payoff,[18] not the *ex post* loss observed with 20/20 hindsight.

Q: Does a capacity option eliminate the utility's electricity spot price risk?

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[15] C.K. Woo, A. Olson and R. Orans, *Benchmarking the Price Reasonableness of an Electricity Tolling Agreement*, 17(5) ELECTRICITY JOURNAL 65-75 (2004).

[16] C.K. Woo, I. Horowitz, A. Olson, B. Horii and C. Baskette, *Efficient Frontiers for Electricity Procurement by An LDC with Multiple Purchase Options*, 34 OMEGA 70–80 (2006).

[17] D. Lloyd, C.K. Woo, M. Borden, R. Warrington and C. Baskette, *Competitive Procurement and Internet-based Auction: Electricity Capacity Option*, 17(4) ELECTRICITY JOURNAL 74-78. (2004).

[18] For a regression-based approach to compute the expected payoff of a capacity call option, see J. Moore, C.K. Woo, B. Horii, S. Price and A. Olson, *Estimating the Option Value of a Non-firm Electricity Tariff*, 35 Energy 1609-1614 (2010).

A: No. The capacity option can only cap the utility's exposure to very high electricity spot prices for the contracted amount of electricity. It does not eliminate the utility's electricity spot price risk.

Q: What is your finding from the preceding discussion?

A: An electric utility faces procurement cost risks that may be mitigated via generation ownership, electricity forward contracts, tolling agreements, and capacity options. However, the utility continues to face electricity and natural gas spot price risks. Finally, the prudence of the utility's risk management activities should not be based on the utility's *ex post* loss observed with 20/20 hindsight.

II. CROSS HEDGING

Q: What is cross hedging?

A: Cross hedging entails using a futures contract for one commodity whose spot price moves very closely with the spot price of another commodity to be hedged.[19] Cross hedging is useful when one wants to hedge the price of a commodity for which there is no active futures trading (e.g., natural gas delivered at Pacific Gas & Electric ("PG&E") Citygate in Northern California).[20]

Q: Please describe some examples of cross hedging.

A: These are examples for commodities which have no active futures trading:

- Agricultural commodities.[21] There is no active futures trading for sunflower oil, grain sorghum, or cull sows. But one can use soybean oil futures to cross hedge the

[19] D.R. Siegel and D.F. Siegel, THE FUTURES MARKETS (Probus Publishing Company, 1990) at 106.
[20] C.K. Woo, A. Olson and I. Horowitz, *Market Efficiency, Cross Hedging and Price Forecasts: California's Natural-Gas Markets*, 31 ENERGY 1290-1304 (2006).
[21] J. Graff, T. Schroder, R. Jones and K. Dhuyvetter, CROSS HEDGING AGRICULTURAL COMMODITIES (Kansas State University Agricultural Experiment Station and Cooperative Extension Service, 1997); J. Graff, T. Schroder and R. Jones and K. Dhuyvetter, CROSS HEDGING CULL COWS (Kansas State University Agricultural Experiment Station and Cooperative Extension Service, 1997).

sunflower oil price, corn futures to cross hedge the grain sorghum price, and lean hog futures to cross hedge the cull sow price.

- Jet fuel.[22] There is no active futures trading for jet fuel, but one can use heating oil futures to cross hedge the jet fuel price.
- Ethanol.[23] There is no active futures trading for ethanol, but one can use gasoline futures to cross hedge the ethanol price.
- Natural gas.[24] There is no active futures trading for natural gas delivered at PG&E Citygate, but one can use natural gas futures for Henry Hub delivery to cross hedge the PG&E Citygate price.
- Electricity.[25] There is no active futures trading for electricity delivered at the Mid-Columbia ("Mid-C") hub in the Pacific Northwest, but one can use natural gas futures for Henry Hub delivery to cross hedge the Mid-C electricity spot price.

Q: Is cross hedging "akin to placing a bet in the stock market in hopes of generating enough cash to pay for a future variable expense"? (Staff Report B, p.10)

A: No. This is because "[i]f the price of the underlying [commodity] and the price to be hedged are perfectly correlated, one can construct a perfect hedge,"[26] resulting in price certainty for the hedged commodity.

[22] D.A. Carter, D.A. Rogers and B.J. Simkins, FUEL HEDGING IN THE AIRLINE INDUSTRY: THE CASE OF SOUTHWEST AIRLINES (Department of Finance, Oklahoma State University, no date), available at: http://www.sba.pdx.edu/faculty/danr/danraccess/courses/fin562/hedging_case_crj_submission.pdf

[23] J.R.V. Franken and J.L. Parcell, *Cash Ethanol Cross-Hedging Opportunities*, 35 JOURNAL OF AGRICULTURAL AND APPLIED ECONOMICS 509-516 (2003).

[24] C.K. Woo, A. Olson and I. Horowitz, *Market Efficiency, Cross Hedging and Price Forecasts: California's Natural-Gas Markets*, 31 ENERGY 1290-1304 (2006).

[25] C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011).

[26] D.R. Siegel and D.F. Siegel, THE FUTURES MARKETS (Probus Publishing Company, 1990) at 106.

III. USING NATURAL GAS FUTURES TO CROSS HEDGE NATURAL GAS SPOT PRICES

Q: What is the source of the hypothetical utility's natural gas spot price risk?

A: It is the utility's natural gas-fired generation and tolling agreements, as explained in Section I.

Q: Does the New York Mercantile Exchange ("NYMEX") natural gas futures contract's point of delivery usually match the electric utility's local natural gas hub?

A: No. The delivery point of the NYMEX natural gas futures is Henry Hub in Louisiana,[27] while the utility's local hub could be any one of the hubs in Figure 1 below.

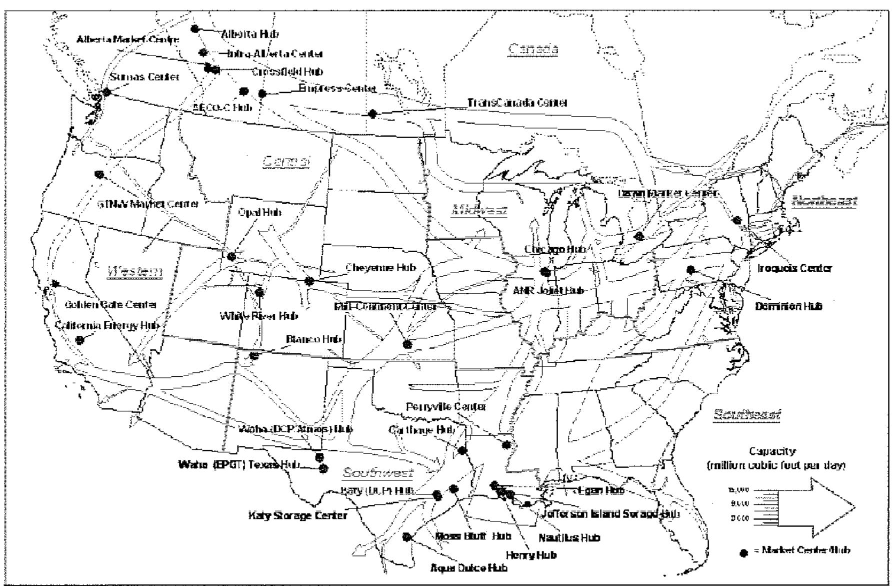

Figure 1: Natural gas market hubs in North America.[28]

Q: Please describe the relationship between the natural gas spot price *H* ($/MMBTU) at Henry Hub and the natural gas spot price *G* ($/MMBTU) at a local hub.

[27] http://www.cmegroup.com/trading/energy/natural-gas/natural-gas_contract_specifications.html
[28] http://www.eia.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/MarketCenterHubsMap.html

A: Empirical evidence suggests that the major natural gas hubs in North America are integrated.[29] On average, they follow the law of one price: Local hub price = Cost of transportation + Henry Hub price.[30] Thus, the spot price relationship can be described by the equation below:

$$G \quad = \quad C + H + \varepsilon \qquad (1)$$

where G = local hub spot price; C = cost of transporting natural gas from Henry Hub to the local hub; H = Henry Hub spot price; and ε = random deviation from the law of one price.

Q: Absent cross hedging, what is the utility's natural gas spot price risk?

A: For ease of exposition, I assume C is a constant, reflecting the average toll charge for natural gas transportation. Then the price risk is the standard deviation of G, or the square root of the following price variance under the assumption that H and ε are uncorrelated:[31]

$$\mathrm{Var}(G) \quad = \quad \mathrm{Var}(H) + \mathrm{Var}(\varepsilon). \qquad (2)$$

Q: Please describe how to use natural gas futures to cross hedge the local hub price.

A: For simplicity, consider a two-period example in which the utility wishes to buy natural gas futures in Period 1, so as to cross hedge the local hub price in Period 2. Cross hedging in this case entails the following transactions:

(1) Buy natural gas futures at $\$F$ per MMBTU in Period 1 for delivery in Period 2.

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[29] A. Serletis, *Is There an East-West Split in North American Natural Gas Markets*? 18(1) THE ENERGY JOURNAL 47-63 (1997).

[30] C.K. Woo, A. Olson and I. Horowitz, *Market Efficiency, Cross Hedging and Price Forecasts: California's Natural-Gas Markets*, 31 ENERGY 1290-1304 (2006).

[31] A.M. Mood, F.A. Graybill and D.C. Boes, INTRODUCTION TO THE THEORY OF STATISTICS (McGraw Hill, 1974) at 178.

(2) Take delivery at Henry Hub, pay \$$F$ per MMBTU, and resell the delivered natural gas at \$$H$ per MMBTU in Period 2, yielding \$$(H – F)$ per MMBTU.[32]

(3) Buy natural gas with local delivery at \$$G$ per MMBTU in Period 2.

The above transactions imply that the net price in Period 2 for local natural gas is:

$$\begin{aligned} G' &= C + H - (H - F) + \varepsilon \\ &= C + F + \varepsilon \end{aligned} \tag{3}$$

Since the futures price F has been contracted in Period 1, it is a fixed number in Period 2. Thus, cross hedging replaces the potentially volatile Henry Hub price H in Period 2 with the locked-in futures price F in Period 1.

Q: Is cross hedging in this case always *ex post* profitable?

A: No. Transaction (2) in the above Q&A may yield an *ex post* gain of $(H – F) > 0$, or an *ex post* loss of $(H – F) < 0$. Hence, it is inappropriate to judge cross hedging's prudence based on the *ex post* loss observed with 20/20 hindsight.

Q: Does cross hedging reduce the utility's exposure to local natural gas spot price risk?

A: Yes. Since F is a fixed number with zero variance, the variance of the hedged price G' is:

$$\mathrm{Var}(G') = \mathrm{Var}(\varepsilon), \tag{4}$$

which is less than the variance of the unhedged price G given by equation (2).

32 A description of the Henry Hub natural gas futures is available at: http://www.cmegroup.com/trading/energy/natural-gas/natural-gas_learn_more.html; the contract specifications are available at: http://www.cmegroup.com/trading/energy/natural-gas/natural-gas_contract_specifications.html.

Q: How do you measure the effectiveness of cross hedging?

A: To measure cross hedging's effectiveness, I use

$$E = 1 - \mathrm{Var}(G') / \mathrm{Var}(G), \tag{5}$$

the percentage reduction in the unhedged price's variance.[33]

Q: When is cross hedging likely effective in this case?

A: When $E = 1$, cross hedging is completely effective. This occurs when $\mathrm{Var}(\varepsilon) = 0$ and the Henry Hub and local hub spot prices are perfectly correlated. Hence, cross hedging is likely to be highly effective when the Henry Hub and local hub prices are highly correlated.

Q: What are the MPSC Staff findings regarding GMO's hedging activities related to natural gas used for electric generation?

A: The findings are (a) "Staff found GMO's hedging activities related to natural gas used for electric generation to be in compliance with GMO's natural gas price hedge plan" (Staff Report B, p. 13); and (b) "Staff found no indication GMO's purchases of natural gas for the fifth, sixth and seventh accumulation periods reviewed in this case were imprudent" (Staff Report B, p. 14).

Q: Do the Staff findings reject the use of natural gas futures for cross hedging?

A: No. This is because GMO's hedging activities implement cross hedging, as the natural gas used in GMO's electricity generation has a point of delivery different from Henry Hub.

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[33] C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011).

IV. USING NATURAL GAS FUTURES TO CROSS HEDGE ELECTRICTY SPOT PRICES

A. Approach

Q: Why does the hypothetical utility face electricity spot price risk?

A: There are two reasons. First, the electricity spot price directly influences the utility's generation dispatch, and hence the per MWh cost of electricity obtained from self-generation or a tolling agreement. Second, the utility may need to sell into (buy from) the electricity spot market to resolve its net long (short) position of surplus (insufficient) generation.

Q: Please describe the relationship between the on-peak (e.g., the Mid-C on-peak hours are 06:00 – 22:00, Monday-Saturday, excluding WECC holidays) electricity spot price *P* ($/MWh) at a local hub and the natural gas spot price *H* ($/MMBTU) at Henry Hub.

A: Empirical evidence suggests that the relationship can be described by the following regression:[34]

$$P = \alpha + \beta H + \mu \qquad (6)$$

where α = intercept, β = slope coefficient, and μ = random error with zero mean and finite variance. The intercept α in equation (6) aims to capture the average price effect of factors unrelated to the natural gas spot price (e.g., weather). The slope coefficient $\beta > 0$ measures the effect of a $1 increase in the Henry Hub natural gas spot price on the

[34] C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011).

electricity spot price. The random error μ is the electricity spot price deviation from the regression line.

Q: Absent cross hedging, what is the electricity spot price risk?

A: To simplify the derivation of this risk, I assume that α and β are known.[35] Now, the price risk is the standard deviation of P, which is the square root of the following price variance under the assumption that H and μ are uncorrelated:[36]

$$\text{Var}(P) \quad = \quad \beta^2\ \text{Var}(H) + \text{Var}(\mu). \qquad (7)$$

Q: Is the variance of the unhedged electricity spot price given by equation (7) similar to that of the unhedged natural gas spot price given by equation (2)?

A: Yes. This suggests that natural gas futures can be used to cross hedge the electricity spot price.

Q: Please describe how to use natural gas futures contracts to cross hedge the on-peak electricity spot price.

A: For simplicity, consider a two-period example in which the utility wishes to buy natural gas futures in Period 1, so as to cross hedge the electricity spot price in Period 2. Cross hedging in this case entails the following transactions:

(1) Buy β MMBTU of natural gas futures at \$$F$ per MMBTU in Period 1 for delivery in Period 2.

(2) Take β MMBTU delivery at Henry Hub, pay \$$F$ per MMBTU, and resell the delivered natural gas at \$$H$ per MMBTU in Period 2, yielding \$$\beta(H-F)$.

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[35] Relaxing this assumption complicates the derivation of the price variance, without qualitatively changing the subsequent discussion. For a discussion on using an estimated regression to derive the electricity spot price variance, see C.K. Woo, I. Horowitz and K. Hoang, *Cross Hedging and Value at Risk: Wholesale Electricity Forward Contracts*, 8 ADVANCES IN INVESTMENT ANALYSIS AND PORTFOLIO MANAGEMENT 283-301 (2001).

[36] A.M. Mood, F.A. Graybill and D.C. Boes, INTRODUCTION TO THE THEORY OF STATISTICS (McGraw Hill, 1974) at 178.

(3) Buy spot electricity at \$$P$ per MWh in Period 2.

Under cross hedging, the net electricity spot price that the utility would pay is:

$$P' = \alpha + \beta H + - \beta (H - F) + \mu$$

$$= \alpha + \beta F + \mu \qquad (8)$$

Equation (8) shows that cross hedging replaces the potentially volatile Henry Hub price H in Period 2 with the locked-in futures price F in Period 1.

Q: Is cross hedging the electricity spot price always *ex post* profitable?

A: No. Transaction (2) in the above Q&A may yield an *ex post* gain of $\beta (H - F) > 0$, or an *ex post* loss of $\beta (H - F) < 0$. Hence, it is inappropriate to judge cross hedging's prudence based on the *ex post* loss observed with 20/20 hindsight.

Q: Does cross hedging reduce the utility's exposure to electricity spot price risk?

A: Yes. Since F is a fixed number with zero variance, the variance of the hedged price P' is:

$$\text{Var}(P') = \text{Var}(\mu), \qquad (9)$$

which is less than the variance of the unhedged price P given by equation (7).

Q: How do you measure the effectiveness of natural gas futures in cross hedging the electricity spot price?

A: To measure the effectiveness of cross hedging, I modify equation (5) as follows:

$$E = 1 - \text{Var}(P') / \text{Var}(P), \qquad (10)$$

the percentage reduction in the variance of the unhedged electricity spot price.

Q: When is cross hedging likely effective in this case?

A: When $E = 1$, cross hedging is perfectly effective. This occurs when $\text{Var}(\mu) = 0$ and the electricity spot price and the Henry Hub natural gas spot price are perfectly correlated.

Hence, cross hedging is likely to be highly effective when the two spot prices are highly correlated.

B. **<u>Relationship Between Electricity and Natural Gas Spot Prices</u>**

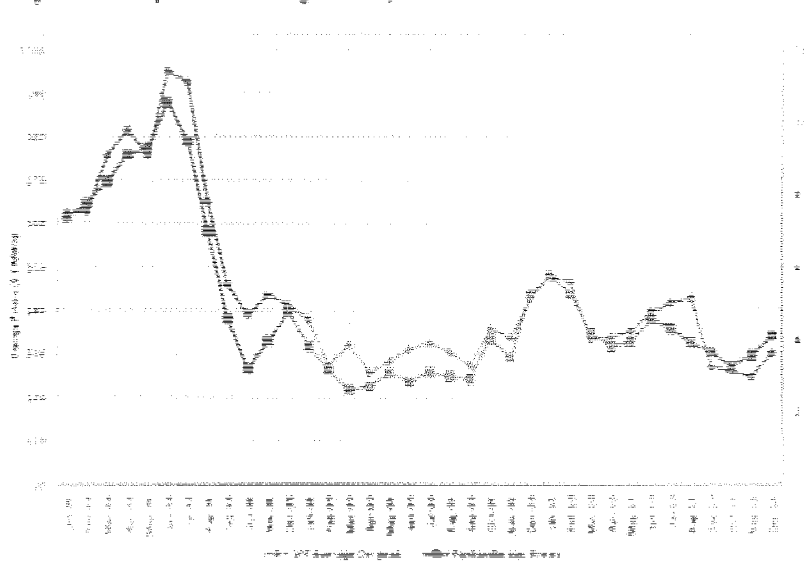
Q: What is the empirical basis for using natural gas futures to cross hedge the electricity spot price?

A: It is the observed relationship between the electricity and natural gas spot prices.

Q: Please describe this relationship in the Southwest Power Pool ("SPP").

A: "Figure II.6 [below] compares the average Panhandle hub gas price and the SPP monthly average price for 2008-2010. Gas prices are very closely associated with average system prices in the SPP region. This is logical, because the marginal resources that set overall prices are most often gas units."[37]

Figure II.6 Comparison of Average Monthly SPP Prices and Panhandle Natural Gas Prices



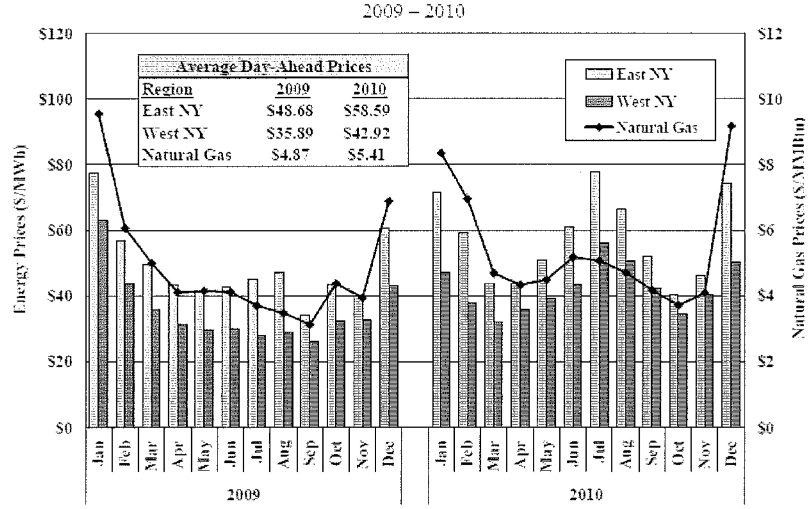
Q: Is the above relationship observed elsewhere in the US?

[37] SPP, 2010 STATE OF THE MARKET (Southwest Power Pool, 2011) at 36; available at: http://www.spp.org/publications/2010-State-of-the-Market-Report.pdf

A: Yes, as evidenced by the statements from the state of the market reports for the following jurisdictions:

- New York Independent System Operator ("NYISO"). "Although much of the electricity used by New York consumers is generated from hydro, nuclear, and coal-fired generators, natural gas units are usually the marginal generation units that set market clearing prices, especially in Eastern New York. This is evident from the strong correlation of electricity prices with natural gas prices shown in the figure [below]."[38]

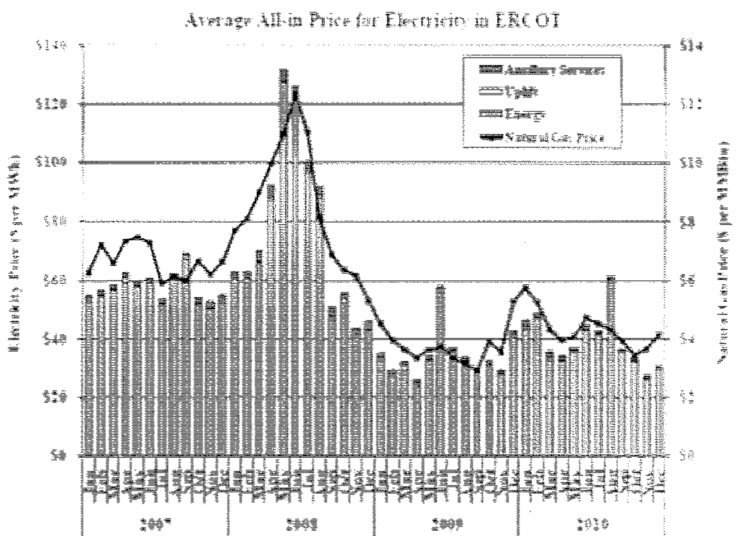
Figure 1: Day-Ahead Energy and Natural Gas Prices
2009 – 2010



- Electricity Reliability Council of Texas ("ERCOT"). "[T]he changes in energy prices from 2009 to 2010 were largely a function of natural gas price movements. … The figure [below] indicates that natural gas prices were a primary driver of the trends in electricity prices from 2007 to 2010. Again, this is not surprising given that natural gas is a widely-used fuel for the production of electricity in ERCOT, especially

[38] D.B. Patton, P. LeeVanShaick and J. Chen, 2010 STATE OF THE MARKET REPORT FOR THE NEW YORK ISO MARKETS (Potomac Economics, 2011) at 23; available: http://www.potomaceconomics.com/uploads/nyiso_reports/NYISO_2010_Final.pdf

among generating units that most frequently set the balancing energy market prices in the zonal market or locational marginal prices in the nodal market."[39]

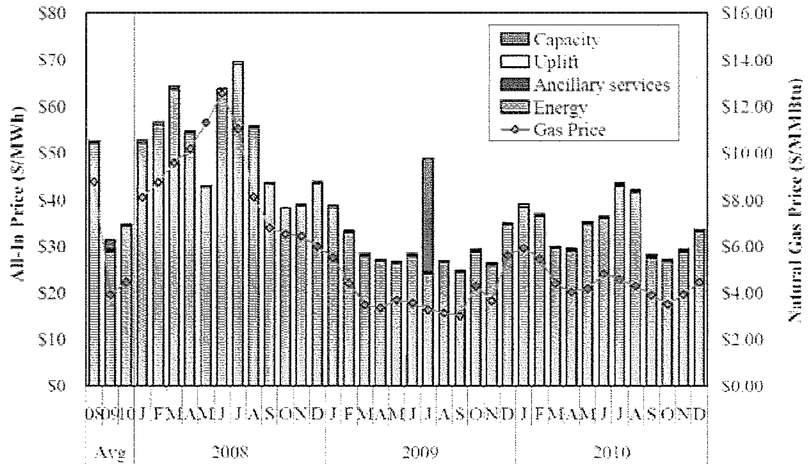


- Midwest Independent Transmission System Operator ("MISO"). "The figure [below] shows that energy price fluctuations are driven in large part by fuel prices as expected. This relationship exists because fuel costs represent the majority of most suppliers' marginal production costs. Since suppliers in a competitive market have an incentive to offer supply at marginal cost, changes in fuel prices translate to changes in offer prices when the market performs competitively."[40]

[39] Potomac Economics, 2010 STATE OF THE MARKET REPORT FOR THE ERCOT WHOLESALE ELECTRICITY MARKETS (2011) at iii; available at:http://www.potomaceconomics.com/uploads/ercot_reports/2010_ERCOT_SOM_REPORT.pdf

[40] Potomac Economics, 2010 STATE OF THE MARKET REPORT FOR THE MISO ELECTRICITY MARKETS (2011) at vi; available at: http://www.potomaceconomics.com/uploads/midwest_reports/2010_State_of_the_Market_Report_Final.pdf

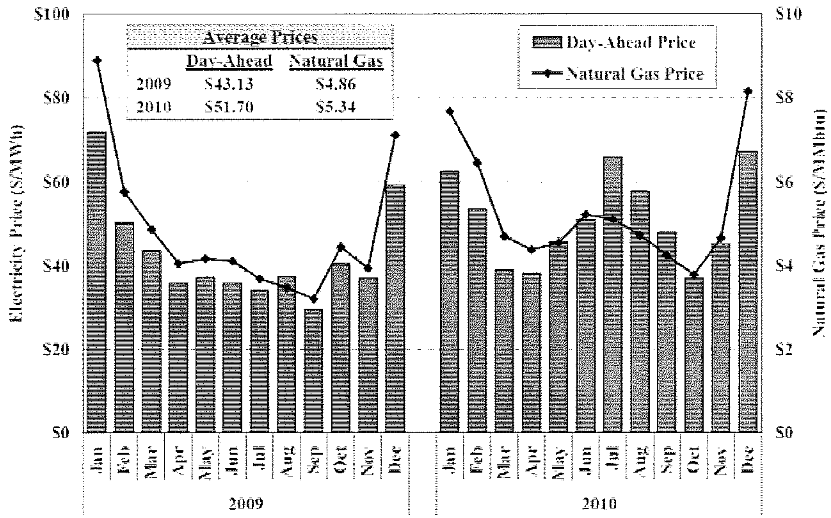
Figure E-1: All-In Price of Electricity
2008-2010



- ISO-New England ("ISO-NE"). "The figure [below] shows that natural gas price fluctuations were a significant driver of variations in monthly average electricity prices in 2009 and 2010 as expected. … Low-cost coal and nuclear resources typically produce at full output, while natural gas-fired resources are on the margin and set the market clearing price in most hours. Therefore, electricity prices should be correlated with natural gas prices in a well-functioning competitive market."[41]

[41] D.B. Patton, P. LeeVanShaick and J. Chen, 2010 ASSESSMENT OF THE ELECTRICITY MARKETS IN NEW ENGLAND (Potomac Economics, 2011) at 2; available at: http://www.potomaceconomics.com/uploads/isone_reports/ISONE_2010_IMMU_Report_Draft_Final_June-11.pdf

Figure 1: Monthly Average Day-Ahead Prices and Natural Gas Prices
New England Hub, 2009 – 2010



- California Independent System Operator ("CAISO"). "Electric prices in the western states typically follow natural gas price trends because natural gas units are frequently the marginal source of generation in California and other regional markets. In 2010, the load-weighted average price of natural gas in the daily spot markets increased about 17 percent from 2009. This was the primary driver of an increase of about 5 percent in the annual wholesale energy cost per MWh of load served in 2010."[42]

C. <u>Real-world Example</u>

Q: Please describe a real-world example of using natural gas futures to cross hedge the electricity spot price.

A: This example is based on my research done for an electric utility in the Pacific Northwest.[43] The goal was to test if Henry Hub natural gas futures can be used to cross

[42] CAISO, 2010 ANNUAL REPORT ON MARKET ISSUES AND PERFORMANCE (California Independent System Operator, 2011) at 46, footnote omitted; available at: http://www.caiso.com/Documents/2010%20Annual%20report%20on%20market%20issues%20and%20performance/2010AnnualReportonMarketIssuesandPerformance.pdf

[43] C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011).

hedge the on-peak Mid-C electricity spot price in the Pacific Northwest, as shown in Figure 2 below.

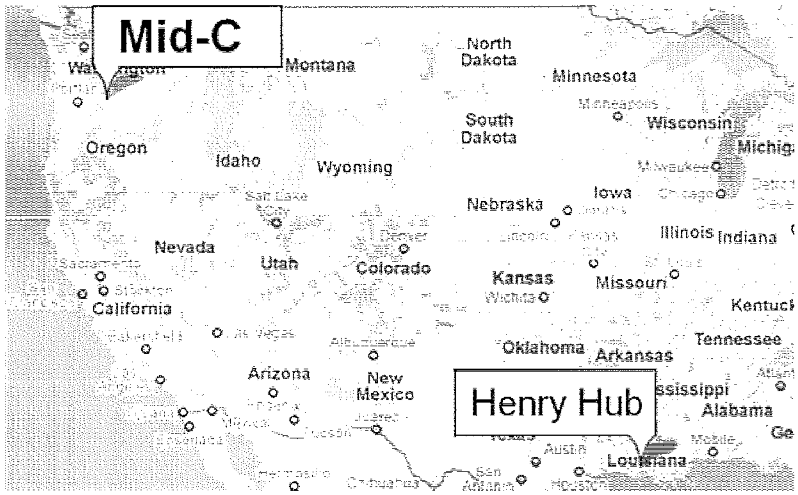


Figure 2: Mid-C hub for spot electricity and Henry Hub for spot natural gas.

Q: Why is this example relevant here?

A: Since the Pacific Northwest is rich in hydro resources that can be dispatched to meet on-peak loads, a finding of effective cross hedging via natural gas futures lends support to its application in regions where marginal generation is fueled by natural gas.

Q: Please describe the Mid-C hub.

A: "The Mid-C hub [is] a major wholesale spot electricity market in the Pacific Northwest. Physically located at several substations along the Columbia River in central Washington, the Mid-C hub is an intersection point for several regional transmission systems, the most prominent of which is the federal Bonneville Power Administration (BPA). The area houses several large hydroelectric dams, including the Grand Coulee (6089MW) and Dalles (1780MW) dams."[44]

[44] C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011) at 266.

Q: What are the drivers of the Mid-C on-peak electricity spot price?

A: Besides the day-of-week and month-of-year effects, the drivers are temperature, hydro condition, and natural gas price.[45] As shown in the figure below,[46] the monthly correlation between the Mid-C on-peak electricity spot price and Henry Hub natural gas spot price is about 0.8 for August – April. It is much lower for May – July due to the spring runoff when the marginal generation is primarily hydro power.

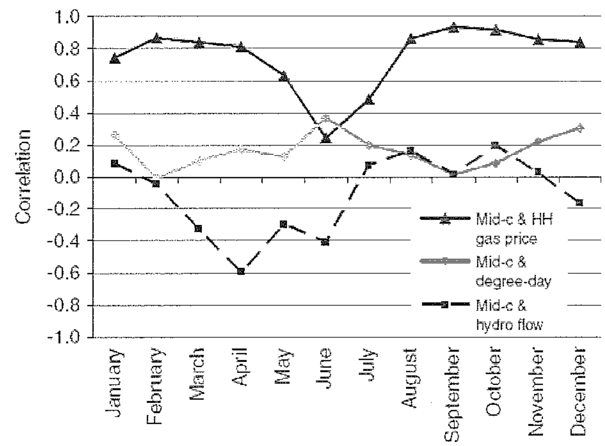


Figure 5. Monthly correlations of daily Mid-C prices with daily degree-day, daily hydro flow, and daily HH natural gas prices from 2003 to 2009.

Q: What is the effectiveness of natural gas futures in cross hedging the Mid-C electricity spot price?

A: The figure below portrays the effectiveness of natural gas futures based on two electricity price regression models.[47] The first model accounts for the effects of weather, hydro flow and natural gas price. The second model only accounts for the electricity price

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[45] C.K. Woo, I. Horowitz, N. Toyama, A. Olson, A. Lai, and R. Wan, *Fundamental Drivers of Electricity Prices in the Pacific Northwest*, 5 ADVANCES IN QUANTITATIVE ANALYSIS OF FINANCE AND ACCOUNTING 299-323 (2007).

[46] This figure is reproduced from C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011).

effect of natural gas price, as given by equation (6) above. This figure shows that the natural gas futures' hedge effectiveness is between 0.5-0.8 for August – April. It is much lower for May – July due to the spring runoff when the marginal generation is hydro power.

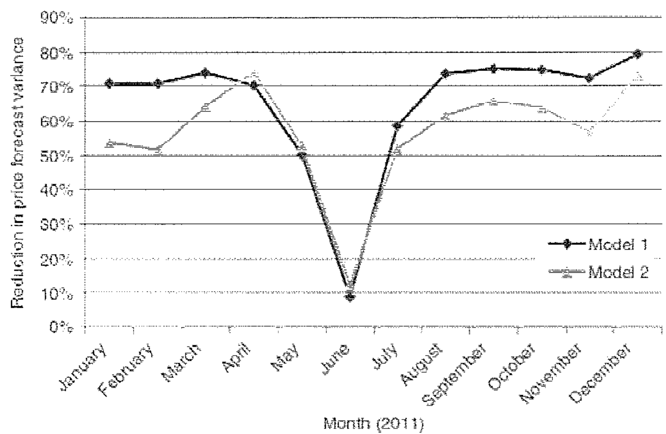

Figure 7. Cross-hedge effectiveness by model, as measured by the reduction in the monthly price-forecast variance due to locking-in the HH natural gas price for delivery months in 2011.

Q: What is the implication of the above figure?

A: Cross hedging is likely to be highly effective when the electricity spot price is highly correlated with the Henry Hub natural gas spot price.

V. <u>RESPONSE TO MPSC STAFF STATEMENTS</u>

Q: Do you agree with the following statement: "...a reasonable person would not buy options to purchase natural gas at fixed prices in the future to hedge against future purchases of electricity in the spot market because there is no direct link between these two markets sufficient upon which to base such 'hedging.'" (Staff Report A, p. 3)?

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[47] This figure is reproduced from C.K. Woo, I. Horowitz, A. Olson, A. DeBenedictis, D. Miller and J. Moore, *Cross-Hedging and Forward-Contract Pricing of Electricity in the Pacific Northwest*, 32 MANAGERIAL AND DECISION ECONOMICS 265-279 (2011).

A: No. I find this statement to be misguided and uninformed. When the electricity spot price is highly correlated with the Henry Hub natural gas spot price, buying natural gas futures at fixed prices can be effective for cross hedging the electricity spot price, as shown in Section IV above.

Q: Do you agree with the two statements listed below?

- **"Staff finds that it was imprudent for GMO to include its hedging costs associated with purchases of natural gas futures contracts to mitigate risk associated with its on-peak spot market purchases…" (Staff Report B, p. 9)**
- **"Staff recommends the Commission find it was imprudent for GMO to link natural gas futures purchase contracts with spot market purchases for purchased power." (Staff Report B, p. 10)**

A: No. I find these statements to be misguided and flawed. When the electricity spot price is highly correlated with the Henry Hub natural gas spot price, one can buy natural gas futures at fixed prices to effectively cross hedge the electricity spot price. While cross hedging can result in *ex post* losses, it is inappropriate to judge cross hedging's prudence based on the *ex post* losses observed with 20/20 hindsight.

Q: Do you agree with the following statement: "Staff knows of no formal organized market that allows for spot purchased power to be hedged which would aid GMO in mitigating the risk associated with buying spot market purchased power" (Staff Report B, p. 9)?

A: No. I find this statement to be misguided, uninformed and erroneous because there is active trading for natural gas futures.[48] Moreover, Section IV shows that one can use natural gas futures to cross hedge the electricity spot price.

Q: Do you agree with the following statement: "Staff concludes that purchasing natural gas futures contracts to mitigate risk associated with the purchase of spot purchase power is imprudent. The two markets (NYMEX Natural Gas and Purchase Power Markets) are not directly linked sufficiently that a prudent person would use option purchases in the natural gas futures market to prudently offset the risk of price volatility in the spot purchased power market" (Staff Report B, pp. 9-10)?

A: No. I find this statement to be misguided, uninformed, and erroneous because (a) the natural gas hubs in North America are tightly integrated; and (b) there is a strong relationship between electricity and natural gas spot prices. As shown in Section IV, cross hedging via natural gas futures can be effective in reducing the electricity spot price risk when electricity and natural gas spot prices are highly correlated.

Q: Do you agree with the following statement: "Under GMO's concept, GMO's actions are akin to placing a bet in the stock market in hopes of generating enough cash to pay for a future variable expense. GMO's "hedging" practice actually increases GMO's risk exposure, to the detriment of GMO's ratepayers; GMO must guess right when placing the bet, otherwise the initial risk exposure to volatile spot purchase power market remains. GMO's linking of natural gas futures contracts with purchases it makes in the spot market for purchased power is imprudent" (Staff Report B, p. 10)?

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[48] http://www.cmegroup.com/trading/energy/natural-gas/natural-gas.html

A: Absolutely not. I find this statement to be completely unfounded. As shown in Section IV, using natural gas futures to cross hedge the electricity spot price can be effective when the electricity and natural gas spot prices are highly correlated. Moreover, equation (9) in Section IV shows that it is not necessary to "guess right" in order to reduce the electricity spot price risk.

Q: What is your finding based on your comments?

A: The MPSC Staff's statements are misguided and uninformed. My findings do not support the MPSC Staff's finding that the use of natural gas futures to cross hedge electricity spot prices is imprudent.

Q: Does this conclude your testimony?

A: Yes, it does.

BEFORE THE PUBLIC SERVICE COMMISSION
OF THE STATE OF MISSOURI

In the Matter of the Third Prudence Review of Costs Subject to the Commission-Approved Fuel Adjustment Clause of KCP&L Greater Missouri Operations Company	))))	Case No. EO-2011-0390

AFFIDAVIT OF C.K. WOO

STATE OF CALIFORNIA)
) **ss**
COUNTY OF SAN FRANCISCO)

C.K. Woo, being first duly sworn on his oath, states:

1. My name is C.K. Woo. I am employed by Energy and Environmental Economics, Inc. in San Francisco, California. I have been retained by Great Plains Energy Services Incorporated, an affiliate of KCP&L Greater Missouri Operations Company, to serve as an expert witness to provide testimony on behalf of KCP&L Greater Missouri Operations Company.

2. Attached hereto and made a part hereof for all purposes is my Direct Testimony on behalf of KC&PL Greater Missouri Operations Company consisting of 30 pages, having been prepared in written form for introduction into evidence in the above-captioned docket.

3. I have knowledge of the matters set forth therein. I hereby swear and affirm that my answers contained in the attached testimony to the questions therein propounded, including any attachments thereto, are true and accurate to the best of my knowledge, information and belief.

Woo Chi-Keung
C.K. Woo

Subscribed and sworn before me this 8th day of February, 2012.

Notary Public

My commission expires: 11-13-13

APRIL M. JOHNSON
COMM. #1868368
NOTARY PUBLIC-CALIFORNIA
SAN FRANCISCO COUNTY
My Comm. Expires Nov. 13, 2013

C.K. Woo

101 Montgomery Street, Suite 1600, San Francisco, CA 94104 415.391.5100
ck@ethree.com

ENERGY AND ENVIRONMENTAL ECONOMICS, INC. San Francisco, CA
Senior Partner 1993 – Present

Dr. Woo specializes in public utility economics, applied microeconomics, and applied finance. With 30 years of experience in the electricity industry, he has testified and prepared expert testimony for use in regulatory and legal proceedings in California, British Columbia and Ontario. He has also filed declaration for and testified in arbitration in connection to contract disputes. Dr. Woo's current research includes electricity deregulation, procurement, risk management, demand response and rationing, avoided cost estimation, integrated resource planning, value of service reliability, and transmission pricing.

Dr. Woo has published over 100 refereed articles on electricity deregulation, procurement, risk management, pricing, rationing, integrated resource planning, value of service reliability, applied microeconomics, and applied finance. These articles appear in such scholarly journals as *Energy Policy, Energy Law Journal, The Energy Journal, Energy, Electricity Journal, Resource and Energy Economics, Energy Economics, IEEE Transactions on Power Systems, Water Resources Research, Managerial and Decision Economics, OMEGA, Journal of Regulatory Economics, Journal of Public Economics, Quarterly Journal of Economics, Journal of Economic Psychology, Economics Letters, Journal of Business Finance and Accounting, and Pacific Basin Finance Journal*. Recognized by *Who's Who in America, Who's Who in Finance and Business, and Who's Who in Science and Engineering*, Dr. Woo is (a) an associate editor of *Energy* and their guest editor of a special issue on electricity market reform and deregulation and a special issue on demand response resources; (b) a member of the editorial board of *The Energy Journal* and has served as their guest editor for a special issue on electricity reliability; (c) a guest editor for a special issue of *Energy Policy* on renewable energy (d) an affiliate with Hong Kong Energy Studies Centre, Baptist University of Hong Kong; and (e) an adjunct professor of economics at the City University of Hong Kong.

CITY UNIVERSITY OF HONG KONG Hong Kong, China
Associate Professor, Department of Economics and Finance *1991 – 1993*

Dr. Woo analyzed the economic impacts of supply shortage on consumers, resulting in a series of publications on water and electricity rationing. He also performed specification tests of econometric models of stock returns. As a consultant, he performed marginal costing, demand-side-management evaluation and reliability planning which led to several publications on local integrated resource planning and T&D costing.

ANALYSIS GROUP, INC. San Francisco, CA
Senior Associate 1987 – 1991

Dr. Woo was responsible for applied microeconomics, outage cost estimation, reliability planning, and electricity pricing. He was the primary consultant to several utilities for outage cost estimation and reliability differentiation. His extensive publications in these two areas are widely cited by other researchers. He also performed economic analysis of mergers and acquisition with a primary focus on the anti-trust aspect of market power, with the resulting findings filed with both state and federal courts.

PACIFIC GAS AND ELECTRIC COMPANY San Francisco, CA
Rate Economist 1985 – 1987

Dr. Woo revamped PG&E's research on outage cost estimation whose findings appear in a special issue of The Energy Journal focusing on electricity reliability. He also participated in PG&E's preparation of the General Rate Cases.

SACRAMENTO MUNICIPAL UTILITIES DISTRICT Sacramento, CA
Econometrician 1984 – 1985

Dr. Woo was responsible for demand estimation and load forecasting. The results from his study guided SMUD's resource planning.

PACIFIC GAS AND ELECTRIC COMPANY San Francisco, CA
Rate Economist 1982 – 1984

Dr. Woo was responsible for time-of-use (TOU) demand analysis and TOU pricing mandated by the CPUC. This work resulted in a performance award from PG&E and several publications.

CALIFORNIA ENERGY COMMISSION Sacramento, CA
Research Assistant 1978 – 1982

Dr. Woo was the primary author of the life cycle costing model used by the CEC to analyze solar energy and other DSM measures. He testified before the CPUC on the economics of solar financing.

Education

University of California Davis, CA
Ph.D. in Economics

Thesis: The non-parametric approach to production analysis: a case study on a regulated electric utility.

Queen's University Kingston, Ontario
M.A. in Economics

Concordia University Montreal, Quebec
B. Comm. in Economics

Invited Lectures

1. *"Wind Generation Development and Incentive for Dispatchable Thermal Generation Investment," University of Texas (Austin) Energy Symposium, October 13, 2011.*

2. *"Renewable Portfolio Standards, Electricity Pricing and Energy Efficiency," Conference of the Electric Power Supply Industry (CEPSI) October 27-31, 2008 Macau.*

3. *"A Critical Assessment of the Hong Kong Government's Proposed Post-2008 Regulatory Regime for Local Electricity Utilities," Elizabeth Chan Cheng E-Lay Geography Academic Seminar, March 16, 2006, Hong Kong Baptist University.*

4. *"Israeli Reform," Electricity Industry Reform in Small Markets – Lessons for Hong Kong: Lunch and Seminar, October 12, 2004, sponsored by Hong Kong Electric Company, UBS, and Mallesons Stephen Jaques.*

5. *"Recent Contributions to Customer Outage Cost Estimation," Workshop on Energy Load Management, July 1988, Israel Ministry of Energy and Infrastructure.*

Testimony

1. *Orans, R. and C.K. Woo (2008) Direct Testimony: Transmission Rate Design for Hydro-Québec TransÉnergie (HQT) before the Régie.*

2. *Woo, C.K. (2004) Electricity Price Forecast: 2001-2030, and Response to Rebuttal Testimony of William A. Monsen; In the Matter of the Application for Reduction of Assessment of Geysers Power Company, LLC, Sonoma County Assessment Appeals Board, Application Nos.: 01/01-137 through 157.*

3. *Woo, C.K. (2004) Declaration of Dr. C.K. Woo in support of Micrel Inc.'s final offer: Micrel Inc. v. Chevron Energy Solutions, LP.*

4. *Woo, C.K. (2002) Rebuttal Testimony filed on the behalf of Southern California Water Company before the California Public Utilities Commission.*

5. *Woo, C.K. and P.D. Ferguson (1999) Comments on the Ontario Energy Board Staff's Draft Electric Distribution Rate Handbook submitted to Ontario Energy Board on the behalf of The Upper Canada Energy Alliance.*

6. *Woo, C.K. (1996) Direct Testimony, Industrial Service Options Application, prepared for B.C. Hydro.*

7. *Woo, C.K. (1996) Rebuttal Testimony Presenting an Analysis of the Use of Class-based Value of Service for Marginal Generation Capacity Costs, filed with California Public Utilities Commission for Pacific Gas Electric Company's 1996 General Rate Case.*

8. *Woo, C.K. (1979) Economics of Solar Financing, Order Instituting Investigation 42 Testimony submitted to the California Public Utilities Commission for the California Energy Commission.*

RESEARCH

Special issues

1. *Woo, C.K., L.C.H. Chow and T. Owen, editors (2011) Special Issue on Renewable Energy, Energy Policy, 39:7.*

2. *Woo, C.K. and L. Greening, editors (2010) Special Issue on Demand Response Resources, Energy, 35.*

3. *Woo, C.K., L.C.H. Chow and N. Lior, editors (2006) Special Issue on Electricity Market Reform and Deregulation, Energy, 31:6-7.*

4. *Munasinghe, M., C.K. Woo and H.P. Chao, editors (1988) Special Electricity Reliability Issue, The Energy Journal, 9.*

Refereed Publications

Electricity Deregulation

1. *Tishler, A. and C.K. Woo (2010) "Principles of Regulation in Electricity Markets," The Economic Quarterly (in Hebrew), 57:1, 77-97.*

2. *Woo, C.K., I. Horowitz and A. Tishler (2009) "A Critical Assessment of the Macau SAR Government's Proposed Post-2010 Regulatory Regime," Electricity Journal, 22:3, 87-96.*

3. *Woo, C.K. and J. Zarnikau (2009) "Will Electricity Market Reform Likely Reduce Retail Rates?" Electricity Journal, 22:2, 40-45.*

4. *Tishler, A., I. Milstein and C.K. Woo (2008) "Capacity Commitment and Price Volatility in a Competitive Electricity Market," Energy Economics, 30, 1625-1647.*

5. *Tishler, A., J. Newman, I. Spekterman and C.K. Woo (2008) "Assessing the Options for a Competitive Electricity Market in Israel," Utilities Policy, 16, 21-29.*

6. *Tishler, A. and C.K. Woo (2007) "Is Electricity Deregulation Beneficial to Israel?" International Journal of Energy Sector Management, 1(4): 322-341.*

7. *Woo, C.K., I. Horowitz and A. Tishler (2006) "A Critical Assessment of the Hong Kong Government's Proposed Post-2008 Regulatory Regime for Local Electricity Utilities," Energy Policy, 34, 1451-1456. (Lead article)*

8. *Woo, C.K., A. Olson, I. Horowitz and S. Luk (2006) "Bi-directional Causality in California's Electricity and Natural-Gas Markets," Energy Policy, 34:15, 2060-2070.*

9. *Woo, C.K., M. King, A. Tishler and L.C.H. Chow (2006) "Costs of Electricity Deregulation," Energy, 31:6-7, 747-768. (Lead article after Guest Editors' Introduction, one of the 25 most downloaded articles)*

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