BEFORE THE OFFICE OF ADMINISTRATIVE HEARINGS
FOR THE MINNESOTA PUBLIC UTILITIES COMMISSION
STATE OF MINNESOTA

In the Matter of the Further Investigation into
Environmental and Socioeconomic Costs
Under Minnesota Statute 216B.2422, Subdivision 3

OAH Docket No. 80-2500-31888

MPUC Docket No. E-999-CI-14-643

Exhibit ______

Rebuttal Testimony and Exhibits of

Dr. William Wecker

August 12, 2015

Q. Please state your name, address, and occupation.

A. My name is William Wecker.

My professional address is 270 E. Simpson Avenue, P.O. Box 1010, Jackson, Wyoming, 83001.

I am a statistician and applied mathematician. I am currently President of William E. Wecker Associates, Inc., an applied mathematics consulting firm located in Jackson, Wyoming.

Q. Did you previously submit testimony in this proceeding?

A. No.

Q. Please describe your educational background and professional experience.

A. I received the Bachelor of Science degree (Basic Sciences) from the United States Air Force Academy in 1963. I received both the Master of Science degree (Operations Research, 1970) and Doctor of Philosophy degree (Statistics and Management Science, 1972) from the University of Michigan. I have served on the faculties of the University of Chicago, the University of California, Davis, and Stanford University where I taught statistics and applied mathematics at the graduate level. I have performed research in statistical theory, statistical methods, and applied mathematics since 1972. I have served as associate editor of the *Journal of the American Statistical Association* for four years and of the *Journal of Business and Economic Statistics* for eighteen years. These qualifications and a list of my professional publications are shown in my *curriculum vitae*, which is attached as Wecker Exhibit 1.

Q. Have you reviewed pre-filed direct testimony in this proceeding?

A. Yes. I reviewed written testimony by Nicholas Martin.

Q. Have you prepared a rebuttal report that responds to this pre-filed testimony?

A. Yes, I have prepared a report, which is attached as Wecker Exhibit 2.

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Exhibit 1

To

Rebuttal Testimony of

Dr. William Wecker

August 12, 2015

February 2015

WILLIAM E. WECKER

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EDUCATION

B.S.	Basic Science, U.S. Air Force Academy (1963)
M.S.	Operations Research, University of Michigan (1970)
Ph.D.	Statistics and Management Science, University of Michigan (1972)

EMPLOYMENT

1963-1967	Fighter pilot, U.S. Air Force
1968-1969	Chief of Protocol, U.S. Air Force, Berlin, Germany
1970-1972	Graduate Student, University of Michigan
1973-1976	Assistant Professor, Graduate School of Business, University of Chicago
1977-1983	Associate Professor, Graduate School of Business, University of Chicago
1984-1985	Associate Professor, Graduate School of Management, University of California, Davis
1985-1989	Professor, Graduate School of Management, University of California, Davis
1994-1998	Consulting Professor of Law, School of Law, Stanford University
1990-	President, William E. Wecker Associates, Inc.

ACTIVITIES

1977-1981	Associate Editor (Theory and Methods), Journal of the American Statistical Association
1981-1999	Associate Editor, Journal of Business and Economic Statistics
1990-1992	Management Committee, Journal of Business and Economic Statistics
1976-1994	Seminar Leader, NSF/NBER Seminar on Time Series Analysis
1993-1994	National Advisory Council on Environmental Policy and Technology (Lead Subcommittee)
Member of:	American Association for the Advancement of Science American Statistical Association Institute of Mathematical Statistics Society for Risk Analysis

PUBLICATIONS

"A Nonparametric Approach to the Construction of Prediction Intervals for Time Series Forecasts" (with W. A. Spivey), Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1972.

"Regional Economic Forecasting: Concepts and Methodology" (with W. A. Spivey), The Regional Science Association Papers, Vol. 28, 1972, pp. 257-276.

"On the Weighted Average Cost of Capital" (with R. R. Reilly), Journal of Financial and Quantitative Analysis, January 1973, Vol. VIII, pp. 123-126.

"On Random Walks with Absorbing Barriers" (with Thomas E. Morton), Proceedings of the Business and Economic Statistics Section-- American Statistical Association, 1973.

"Prediction Methods for Censored Time Series," Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1974.

"More on the Weighted Average Cost of Capital: Reply" (with R. R. Reilly), Journal of Financial and Quantitative Analysis, June 1975.

"Predicting Mail Order Demand for Style Goods," Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1975.

"The Prediction of Turning Points," Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1976.

"Bounds on Absorption Probabilities for the m-Dimensional Random Walk" (with T. Morton), Journal of the American Statistical Association, March 1977.

"Discounting, Ergodicity and Convergence of Markov Decision Processes" (with T. Morton), Management Science, April 1977.

"Comments on 'Forecasting with Econometric Methods: Folklore versus Fact'," Journal of Business, 1978, pp. 585-586.

"Comment on 'Seasonal Adjustment When Both Deterministic and Stochastic Seasonality Are Present'," Proceedings of the NBER-CENSUS Conference on "Seasonal Analysis of Economic Time Series," U.S. Government Printing Office, Washington, D.C., 1978, pp. 274-280.

"Predicting Demand from Sales Data in the Presence of Stockouts," Management Science, 1978, Vol. 34, No. 10, pp. 1043-1054.

"The Time Series Which Is the Product of Two Stationary Time Series," Stochastic Processes and Their Application, 1978, pp. 153-157.

"Predicting the Turning Points of a Time Series," Journal of Business, January 1979, Vol. 52, pp. 35-50.

"A New Approach to Seasonal Adjustment," Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1979.

"Linear and Nonlinear Regression Viewed as a Signal Extraction Problem" (with C. Ansley), Proceedings of the Business and Economic Statistics Section-- American Statistical Association, 1980.

"Asymmetric Time Series," Journal of the American Statistical Association, March 1981.

"Predicting a Multitude of Time Series" (with R. A. Thisted), Journal of the American Statistical Association, September 1981.

"Applications of the Signal Extraction Approach to Regression" (with C. Ansley), Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1981.

"Nonparametric Multiple Regression by Projection Iteration" (with C. Ansley), Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1982.

"The Signal Extraction Approach to Nonlinear Regression and Spline Smoothing" (with C. Ansley), Journal of the American Statistical Association, March 1983.

"Extensions and Examples of the Signal Extraction Approach to Regression" (with C. Ansley), Applied Time Series Analysis of Economic Data, A. Zellner (ed.), Washington, D.C.: Bureau of the Census/ASA, 1983.

"The Signal Extraction Approach to Estimating Income and Price Elasticities: A Data Example" (with C. Ansley), Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1983.

"A Nonparametric Bayesian Approach to the Calibration Problem," (with C. Ansley), Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1984.

"On Dips in the Spectrum of a Seasonally Adjusted Time Series" (with C. Ansley), Journal of Business and Economic Statistics, October 1984.

"Estimating Damages in a Class Action Litigation" (with E. George), Journal of Business and Economic Statistics, April 1985.

"Making Statistics More Effective in Schools of Business: Interdisciplinary Cooperation" (with R. Hamada, J. Patell, R. Staelin), Proceedings of the Business and Economic Statistics Section--American Statistical Association, 1986.

"The Role of Statistics in Accounting, Marketing, Finance and Production" (with R. Hamada, J. Patell, R. Staelin), Journal of Business and Economic Statistics, 1988.

"Assessing the Accuracy of Time Series Model Forecasts of Count Observations," Journal of Business and Economic Statistics, October 1989.

"Impact of the Soviet Grain Embargo; A Comparison of Methods" (with A. Webb, et al), Journal of Policy Modeling, pp. 361-389, 1989.

"Modeling Daily Milk Yield in Holstein Cows Using Time Series Analysis" (with H. Deluyker, et al.), Journal of Dairy Science, pp. 539 - 548, 1990.

"Controlling Emissions from Motor Vehicles: A Benefit-Cost Analysis of Vehicle Emission Control Alternatives" (with L. Lave, et al.), Environmental Science & Technology, August 1990.

"Statistical Estimation of Incremental Cost from Accounting Data" (with R. Weil), Handbook of Litigation Services for Accountants and Lawyers, John Wiley & Sons, 1990.

"Correcting for Omitted-Variables and Measurement-Error Bias in Regression with an Application to the Effect of Lead on IQ" (with M. L. Marais), Journal of the American Statistical Association, June 1998.

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Exhibit 2

To

Rebuttal Testimony of

Dr. William Wecker

August 12, 2015

EXPERT REPORT OF WILLIAM E. WECKER

August 12, 2015

1. My name is William E. Wecker. I am a statistician and applied mathematician. I received the Bachelor of Science degree (Basic Sciences) from the United States Air Force Academy in 1963. I received both the Master of Science degree (Operations Research, 1970) and Doctor of Philosophy degree (Statistics and Management Science, 1972) from the University of Michigan. I have served on the faculties of the University of Chicago, the University of California, Davis, and Stanford University where I taught statistics and applied mathematics at the graduate level. I have performed research in statistical theory, statistical methods, and applied mathematics since 1972. I am currently President of William E. Wecker Associates, Inc., an applied mathematics consulting firm located in Jackson, Wyoming. I am a member of the American Statistical Association, the Institute of Mathematical Statistics, and the Society for Risk Analysis. I have served as associate editor of the *Journal of the American Statistical Association* for four years and of the *Journal of Business and Economic Statistics* for eighteen years. These qualifications and a list of my professional publications are shown in my *curriculum vitae*, which is appended to this report as Attachment A.
2. Counsel for Peabody Energy asked me to review and respond to the direct testimony in this proceeding of Mr. Nicholas F. Martin ("Martin Testimony"), to the extent that his testimony involves or relies upon statistical concepts, theory, and methods.
3. A list of all materials I have considered in forming the opinions expressed in this report is appended to this report as Attachment B.

What Mr. Martin was asked to do, and claims to have accomplished

4. Mr. Martin states that the purpose of his testimony is to answer the following question posed by the Minnesota Public Utilities Commission:[1]

> [W]hether the Federal Social Cost of Carbon is reasonable and the best available measure to determine the environmental cost of CO_2 under Minn. Stat. §216B.2422 and, if not, what measure is better supported by the evidence.

[1] Martin Testimony, pp. 1-2.

5. In response, Mr. Martin asserts that "the methodology to develop the environmental cost of CO_2 … should be based on a balanced consideration" of several criteria including the following broadly statistical and mathematical considerations:[2]

- Reasonably address the inherent uncertainty in estimating climate change damages over almost 300 years,
- Reflect the absence of consensus on discount rate choice,
- **Use statistically sound methods** [boldface added],
- Reflect an appropriate level of risk tolerance,
- Minimize subjective judgments, …

Purportedly applying these criteria, Mr. Martin recommends that the Commission adopt, instead of any single value for the environmental cost of CO_2 (hereinafter "ECC"), "a CO_2 environmental cost range from a low of $12.33 to a high of $41.80 (in 2014 dollars per short ton of CO_2) for emissions in 2020, for example, and other values for other base years.[3]

6. Mr. Martin's proposed ECC ranges are based entirely on the results of calculations performed by the U.S. Government Interagency Working Group ("IWG"[4]) for the purpose of developing the federal Social Cost of Carbon ("SCC") estimates. Though admitting the profound frailty of the assumptions and bases for the IWG calculations,[5] Mr. Martin nevertheless relies on their results for his own proposal to the Commission. In arriving at his own proposal he deviates from the IWG solely with respect to his understanding of the proper way to condense the IWG's calculated results—despite their frailties—into a small number of numeric inputs for decision making. He advises that the Commission may rely on the IWG SCC calculations "*as long as statistical methods are used* [italics added] to derive a range of values rather than a single value."[6] The question then becomes, does Mr. Martin's methodology properly employ "statistically sound methods," in fact, to obtain a proposed ECC range that is conceptually superior to the IWG's federal SCC estimates?

7. Based on my review of his testimony, it is my opinion that Mr. Martin has *failed*, in fact, to employ "statistically sound methods," and thus has *failed* to apply his stated criteria on a

[2] Martin Testimony, p. 2.
[3] Mr. Martin provides such ranges for 2010, 2020, 2030, 2040, and 2050; see Martin Testimony, p. 8.
[4] Martin Testimony, p. 7.
[5] As summarized, for example, in Martin Testimony, pp. 4-7.
[6] Ibid., p. 4.

principled, rigorous basis. As a result, he has *failed* to provide any principled basis for his proposed ECC range of values for the environmental cost of CO_2. Rather, despite a gloss of statistical science, this proposed range is the product of Mr. Martin's entirely arbitrary subjective judgment. In my opinion, by exercising such judgment, Mr. Martin far exceeds the proper scope of application and authority of "statistically sound methods"—even had he properly employed such methods, which he has not—and effectively arrogates to himself the role of a regulatory decision maker on complex questions left *un*resolved by any actual evidence in this proceeding.

How Mr. Martin Arrived at His Recommended "Environmental Cost Range"

8. Mr. Martin takes as given the work product of the U.S. Government Interagency Working Group ("IWG"[7]), as described in an IWG Technical Support Document ("TSD"[8]), concerning their calculations of the federal "social cost of carbon" ("SCC") estimates. The SCC is defined as the present value, as of a chosen base year, of the stream of incremental net costs of the global effects through 2300 of an incremental one-ton CO_2 impulse in the chosen base year.[9] For calculating the SCC, the IWG chose three "integrated assessment models" ("IAMs"[10]), each requiring a number of inputs,[11] some of which are uncertain and therefore represented by subjective probability distributions[12] instead of specific, individual numeric values.

9. Among the IWG's SCC modeling inputs are also socio-economic scenarios ("SESs"[13]) representing potential paths of global population and economic activity through 2300. The

[7] Ibid., p. 7.
[8] Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866; Interagency Working Group on Social Cost of Carbon, United States Government; May 2013, Revised November 2013.
[9] Martin Testimony, p. 11.
[10] Ibid., p. 17.
[11] For example, the discount rate is an input to the IAMs. November 2013 TSD, p. 12; February 2010 TSD, p. 6.
[12] For example, the IWG assumed a probability distribution for equilibrium climate sensitivity. Martin testimony, p. 18.
[13] Martin Testimony, pp. 16-17.

IWG chose five distinct SESs, and used each of them as an input to each IAM, for a total of 15 distinct IAM/SES combinations.

10. Because of the uncertainties in the IWG's modeling inputs, the model outputs are necessarily also uncertain. To account for this form of uncertainty, the IWG employed a "Monte Carlo" ("MC") method:[14] for each uncertain input parameter, draw an exemplar value at random but in accordance with the probability distribution assumed for each input parameter, and calculate the corresponding model output; repeat 10,000 times. This process generated 10,000 streams of estimated future incremental net costs through 2300, for each of 15 IAM/SES combinations, for each of five chosen base years.[15]

11. How to reduce such a stream of net costs through 2300 to a single net cost measured in base-year dollars is itself a complex question.[16] The IWG chose to do this through simple discounting to a present value at a constant discount rate, using three alternative discount rates: 2.5, 3, and 5 percent.[17] This process yields 150,000 present-value cost estimates per discount rate for each base year, for a total of 450,000 cost estimates per base year.

12. The IWG chose to condense this profusion of 450,000 widely disparate[18] cost estimates into just four descriptive statistics for each base year:[19] the simple average of the 150,000 cost estimates for each of the three discount rates (2.5%, 3%, and 5%), and the 95th percentile of the 150,000 cost estimates for a discount rate of 3 percent alone.[20] For example, the IWG reported values of these descriptive statistics for 2015 of $12, $37, $57, and $109, respectively.[21]

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[14] Martin Testimony, p. 18.

[15] Martin Testimony, p. 18.

[16] February 2010 TSD, p. 17: "The choice of a discount rate, especially over long periods of time, raises highly contested and exceedingly difficult questions of science, economics, philosophy, and law."

[17] November 2013 TSD, p. 2.

[18] Martin Testimony, p. 3: "The models used in deriving the SCC predict 450,000 values for any given emissions year, and those values range from negative damages (benefits) to damages of nearly $1,000 per ton of CO_2 emissions."

[19] Values for years between the IWG's decadal base years were calculated by linear interpolation between the base-year values (November 2013 TSD, pp. 12-13).

[20] November 2013 TSD, p. 12.

[21] November 2013 TSD, Table 2, p. 13.

13. For his own testimony in this proceeding Mr. Martin performed no new modeling independently of the IWG's calculations. Instead, he continued to rely on the IWG's profusion of 450,000 cost estimates per base year, unchanged. However, he deviates from the IWG in recommending to the Commission *not* to adopt for the Minnesota ECC the IWG's four descriptive statistics for SCC cost estimates for each base year.[22] Instead, he recommends to the Commission that it adopt a novel condensation (of his own invention) of the 450,000 IWG cost estimates for each base year into just *two* descriptive statistics: the simple average of the three 25th percentiles of the three sets of 150,000 IWG SCC estimates for the three IWG discount rates, and the corresponding simple average of the 75th percentiles.[23,24]

14. In relying on the IWG's SCC modeling outputs for his proposal to the Commission, Mr. Martin implicitly accepts and endorses the IWG's modeling assumptions, including the global scope of the incremental net costs considered by the IWG, the discount rates and equilibrium climate sensitivity applied by the IWG, and the IWG's choices and treatment of IAMs and SESs. I am aware that other experts in this proceeding have criticized and contested these assumptions,[25] and to the extent that these critiques fall within my areas of expertise I agree with them. Solely for the sake of discussion, I have framed my comments below as if the IWG's SCC estimates are indeed relevant and reliable inputs for the determination of a Minnesota ECC, as Mr. Martin assumes. This should not be misunderstood to imply that I agree with or accept Mr. Martin's assumptions in this regard.

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[22] Martin Testimony, pp. 3-4. To the extent that Mr. Martin recommends that the Commission *not* adopt the federal SCC as the Minnesota ECC, I agree with him. Several of my comments in this report on the deficiencies of the support he proffers for his proposed ECC values apply equally to the IWG's own descriptive statistical summary of SCC values.

[23] Martin Testimony, pp. 59-60.

[24] Mr. Martin actually performed an unnecessarily complicated version of this calculation using the so-called "bootstrap" method (Martin Testimony, p. 55). However, as I explain in ¶¶ 37-38 below, this bootstrap calculation is entirely superfluous; what it adds to Mr. Martin's proposal is a mere gloss of statistical science, lacking in any statistical substance.

[25] See, in particular, the Direct Testimony of Anne E. Smith, Ph.D., p. 15: "[T]he IWG's SCC values are based on global damages, not Minnesota damages or U.S. damages. This is inappropriate in the case of an individual state's investment decisions when there are no reciprocal agreements with major emitting nations to also adopt that same SCC." See also, generally, the Direct Testimony of Professor Robert Mendelsohn, June 1, 2015.

Mr. Martin's Complete Failure to Employ "Statistically Sound Methods," or to Consult and Cite Authoritative Statistical Literature Concerning the Statistical Tasks He Undertakes

15. For assessing Mr. Martin's claim to have employed "statistically sound methods," it is necessary to identify what statistical tasks he has actually undertaken, and what statistical methods he has actually applied to those tasks. Throughout his testimony Mr. Martin refers to, discusses, or employs various statistical terms and concepts, including the "mean" or "average," the "median," the "normal distribution," the "tail of [a] distribution," "outliers," "probability," "probabilistic problem," "skewness," "percentiles," "risk tolerance," and the "bootstrap method."[26] Merely using statistical terms, or even performing basic statistical procedures such as calculating averages and percentiles or bootstrapping, does not amount *per se* to employing "statistically sound methods." Rather, the actual, proper employment of a "statistically sound method" entails the application of a well-founded, well-established statistical method appropriate to a well-defined problem of a statistical character. Myriad examples of this process of applying "statistically sound methods" can be found in statistical treatises and scholarly journals.

16. In stark contrast, in his testimony in this proceeding Mr. Martin conspicuously *fails* to employ available, statistically sound methods rooted in decades of published research. Specifically, for arriving at his proposed range, Mr. Martin undertakes to solve two principal, recognizably statistical problems:

    16.1. for each of three discount rates (and five baseline calendar years), combine information from 15 disparate probabilistic forecasts (representing 15 IAM/SES combinations) into a composite probabilistic forecast for use as a decision input; and

    16.2. for each of five baseline calendar years, reduce the three composite probabilistic forecasts to an appropriate summary—i.e., the ECC required by the statute—for serving as a decision-making input for regulators and utilities.

    Both of these statistical problems have been extensively studied over a period of decades and have generated large bodies of peer-reviewed research literature and multiple treatises in the

[26] For example, Martin Testimony, pp. 10, 18, 25-28, 49, and 53-64.

mainstream of statistics and applied mathematics, *none* of which Mr. Martin employs or refers to in support of his proposal to the Commission. Instead, he relies on novel, *ad hoc* procedures of his own invention based on arbitrary, subjective judgments.

Mr. Martin's Failure to Consult or Apply Authoritative Statistical Literature on Combining Probabilistic Forecasts

17. The statistical and mathematical analysis of how best to combine probabilistic forecasts from diverse sources including alternative expert judgments and alternative models for making decisions "under various conditions of uncertainty and partial ignorance" is the subject of a large, decades-old area of study and scholarly literature within the mainstream of statistical science.[27] The subject of this field of study is variously described as combining information, combining expert opinions, or aggregating probability distributions, among other terms.[28]

18. Draper et al. (1992), a frequently referenced survey of these topics sponsored by the U.S. National Research Council, characterizes this subject matter as follows:[29]

> **More Than One Set of Modeling Assumptions.** In many settings in which prediction is the goal, uncertainty about the form of an appropriate model relating the past to the future leads analysts to formulate predictions and uncertainty assessments *using a variety of models of varying degrees of plausibility* [italics added], and the problem of how to combine the information from this ensemble of models arises.

Elsewhere, under the heading of "Forecasting," Draper et al. notes as follows:[30]

> The possibility of more than one plausible model and/or scenario … arises frequently in practice … . It is natural to suppose that one can do better in prediction and uncertainty assessment by combining the information in these forecasts in some way, but how is this to be done sensibly?

[27] Draper, D., Gaver, D. P., et al., 1992, *Combining Information: Statistical Issues and Opportunities for Research*, National Academies Press, whose preface notes, "This report was prepared in response to a request from the National Security Agency to the National Research Council's Committee on Applied and Theoretical Statistics. It surveys how information from a variety of sources is combined, in science and decision-making, to produce more informative summaries and better decisions than those possible based solely on each information source." (p. v).

[28] See, for example, Clemen, R. T., and Winkler, R. L., 1999, "Combining probability distributions from experts in risk analysis," *Risk Analysis*, 19, 187-203, Clemen, Robert T., and Robert L. Winkler, 2007, "Aggregating probability distributions," in *Advances in decision analysis: From foundations to applications* (2007): 154-176, and Gneiting, T., and Ranjan, R., 2013, "Combining predictive distributions," *Electronic Journal of Statistics*, 7(1), 1747–1782.

[29] Draper, op. cit., pp. 23-24.

[30] Ibid., p. 157

In response to this question the authors identify "three schools of thought on what to do in situations in which at least the possibility of several different forecasts arises," the first of which they term "Sensitivity Analysis":[31]

> When the reason for the multiplicity of potential forecasts is uncertainty in models and scenarios, … one standard practice is to use sensitivity analysis …, varying the model and scenario over plausible alternatives and observing the effects of this variation on the resulting predictions and uncertainty assessments. If "all roads lead to Rome," so to speak—that is, if essentially the same results are obtained no matter what reasonable model/scenario choices are made—then the problem of combining several forecasts disappears in the face of their unanimity. But *if the sensitivity analysis reveals sharp differences in forecasts and/or uncertainty about those forecasts* [italics added; cf. Martin Testimony, Figure 2[32]], *usual practice is to express the model/scenario uncertainty that this implies qualitatively, by describing to the decision-maker how the predictions suggested by one set of model/scenario beliefs might be appropriately modified by someone with a different set of beliefs* [italics added].

In proposing to condense the "model/scenario uncertainty" shown in his Figure 2 to a bare two descriptive statistics[33] for purposes of decision-making by utilities and the Commission, Mr. Martin proposes to *suppress* rather than present decision-makers with information on how strongly predictions depend on and are "modified" by alternative combinations of "model/scenario" choices.

19. Clemen and Winkler (1999; 2007), another frequently referenced scholarly survey, reviews several alternative, broad approaches to "Combining Probability Distributions," including various "axiomatic" mathematical and "Bayesian" methods, and concludes as follows:[34]

> We believe that there is no single, all-purpose combining rule or combining process that should be used in all situations. Rather, the design of the combining process … *should depend on the details of each individual situation*. This process design, … should take into account factors such as the nature and importance of the uncertainties, … We believe that a carefully structured and *documented process* is appropriate.
>
> …

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[31] Ibid., pp. 158-159. The second and third of the three approaches identified by Draper et al. are weighted averaging with empirically determined weights, and Bayesian modeling—neither of which Mr. Martin employed for his analysis in this proceeding.

[32] Martin Testimony, p. 24.

[33] That is, averages of 25th and 75th percentiles; see ¶ 13 above.

[34] Clemen and Winkler (1999), op. cit., p. 199, reaffirmed by Clemen and Winkler (2007), op. cit.

> One possible scenario is that the experts are judged to be exchangeable and their probabilities should be treated symmetrically, but *this should be a conscious choice* …. [Italics added]

Mr. Martin, in contrast with this guidance, does not identify any specific method by name or citation, or justify its choice in light of scholarship on this topic and the details of the "individual situation" of the purpose of his testimony in this proceeding, or "document" the basis for his "conscious choice" of his specific, single method for combining probabilistic information over "model/scenario" combinations. Instead, he simply pools indiscriminately the 15 sets of IWG outputs.

20. In sum, in my opinion, rather than select, document, and apply a well-founded, statistically sound method for aggregating the IWG outputs of the 15 IAM/SES combinations for purposes of his proposal to the Commission in this proceeding, Mr. Martin appears simply to exercise his own unprincipled,[35] arbitrary, subjective judgment.

Mr. Martin's Failure to Consult or Apply Authoritative Statistical Literature on Decision Making under Uncertainty

21. The statistical and mathematical analysis of how best to make decisions "under various conditions of uncertainty and partial ignorance" is also the subject of a large, decades-old area of study and scholarly literature within the mainstream of statistical science.[36] This field of study is called "statistical decision theory," and its concrete application to real-world problems is sometimes called "decision analysis."[37]

22. Statistical decision theory models the problem of how best to decide among alternative courses of action whose consequences depend, in part, on an unknown "state of nature."[38] The range of possible values of this state of nature and their relative likelihoods are presumed

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[35] By "unprincipled" I mean lacking apparent, rigorous foundation in established principles of statistics or applied mathematics, or any other explicitly identified or clearly implied field of expertise.
[36] "Decision Theory," *Encyclopedia of Statistical Sciences*, Wiley, 1982, Vol. 2, p. 277.
[37] Ibid., p. 279. See also, for example, Berger, James O., 1993, *Statistical Decision Theory and Bayesian Analysis*, 2nd ed., Springer, 1993, and DeGroot, M. H., 2004, *Optimal Statistical Decisions*, Wiley-Interscience.
[38] I.e., in this proceeding, the unknown, true value of the ECC.

to be described by a probability distribution.[39] For any given state of nature, the consequences of a given action are expressed in terms of a "loss function." In other words, the loss function quantifies the consequence of choosing action A if state of nature S obtains. Statistical decision theory then approaches the decision problem by selecting as the optimum action that action A that minimizes the expected loss given the probability distribution of states of nature S.[40]

23. I understand that the category of decisions most obviously involved in this proceeding is that of resource planning by utilities in conjunction with the Commission. Statistical decision theory provides guidance, in principle, for how to incorporate information about the uncertain cost of carbon emissions into such decisions: develop a loss function that best describes the comprehensive consequences of each available resource planning action as a function of the ECC (among other factors), as well as a probability distribution that best describes the state of knowledge about the value of the ECC (and other factors); choose the action A that minimizes the expected value of this measure of "loss," subject to these probability distributions of factors affecting loss.

24. If selected descriptive statistics are to be derived from a probability distribution that describes the uncertain state of knowledge about the ECC for use as decision-making inputs by utilities and the Commission, on what principled basis should the specific forms[41] of these descriptive statistics be chosen? A statistically sound approach to this question again falls within the scope of statistical decision theory: choosing a particular form of descriptive statistics from among the broad variety of alternatives is itself a decision with consequences, some of whose determinants are uncertain.

25. To choose the forms of these descriptive statistics on a principled basis, it is necessary to consider how the Commission will employ these statistics, and how the consequences that flow from the Commission's actions based on the descriptive statistics will vary as a function of alternative possible choices of these forms. These consequences must again be

[39] I.e., in this proceeding, a combination of the IWG's Monte Carlo calculations for the SCC, as relied upon by Mr. Martin.

[40] "Decision Theory," op. cit., p. 278.

[41] By "forms" of descriptive statistics, I mean the range of concepts including means, median, percentiles, and many other numerical measures of properties of probability distributions.

measured—in principle—in terms of a loss function.[42] This admittedly complex process is a *necessary* conceptual foundation for a statistically sound approach to choosing the forms of descriptive statistics for the Commission to rely on.

26. Choosing the forms of descriptive statistics on this principled basis would also dispense with Mr. Martin's arbitrary, subjective picking of specific percentiles purportedly reflecting appropriate levels of "risk tolerance" for adoption by the Commission.[43]

27. Choosing forms of descriptive statistics without any apparent consideration of these conceptual elements of the decision problem—as Mr. Martin did for his testimony in this proceeding—does not *resolve* this inherent complexity; it merely *ignores* it. And by ignoring it, he effectively makes choices of descriptive statistics with no known, rational connection to the consequences of the choice, but with consequences nonetheless. Choosing forms of descriptive statistics in this unprincipled manner—including, in particular, Mr. Martin's proposal to the Commission in this proceeding[44]—does not reflect the application of statistically sound methods. It reflects, rather, the exercise of unprincipled, arbitrary, subjective judgment.

Mr. Martin's Unprincipled and Incomplete Treatment of Uncertainty

28. By pooling IWG outputs over IAMs and SESs, Mr. Martin implicitly assigns equal "prior" probabilities to the three IAMs and five SESs chosen by the IWG for its SCC calculations, i.e., he treats these alternative modeling approaches as if they are exactly equally likely to represent reality. Similarly, by taking simple averages of 25th and 75th percentiles over the three discount rates chosen by the IWG, Mr. Martin implicitly treats them as uncertain inputs with exactly equal probabilities.

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[42] This is a "second order" loss function compared to the "first order" loss function referred to in ¶ 23 above. That is, the "first order" loss function of ¶ 23 describes consequences of resource planning decision alternatives as a function of possible values of the ECC. This second order loss function describes consequences of using alternative descriptive statistics (e.g., mean, or median, or percentiles, etc.) as the inputs relied upon by the Commission for making the resource planning decisions that incur the first-order consequences.

[43] Martin Testimony, p. 10.

[44] See ¶ 13 above.

29. Without substantial further explanation—which Mr. Martin does not provide—this blithe, implicit reliance on the "principle of indifference"[45] applied to modeling choices made previously by the IWG is ill-founded. Other experts in this proceeding opine, for example, that in the context of SCC modeling the PAGE IAM is materially *less* relevantly applicable than the DICE or FUND IAMs,[46], and that 7%, as opposed to the IWG's three chosen values of 2.5%, 3%, and 5%, is an appropriate discount rate.[47]

30. My review of other expert reports submitted in this proceeding[48] shows that even the broad ranges of uncertainty already reflected in Martin Figure 2[49] and Martin Table 2[50] fail to capture properly the full range of uncertainty associated with the IWG's SCC estimates. Additional uncertainty, *not* accounted for in the IWG's Monte Carlo calculations, arises from ill-founded assumptions and arbitrary inputs used by the IWG when running IAMs. For example, I understand from the reports of Professors Happer, Lindzen, Mendelsohn, and Spencer that the climate sensitivity assumptions employed in the IWG models are likely overstated and, therefore, that SCC estimates based on these models are likely biased high.[51] In other words, the SCC calculated by the IWG is even more uncertain than is accounted for by the wide ranges of uncertainty shown in Figure 2 and Table 2 of Mr. Martin's testimony.

[45] "Keynes (1921, pp. 52-53) referred to the principle as the principle of indifference, formulating it as 'if there is no known reason for predicating of our subject one rather than another of several alternatives, then relatively to such knowledge the assertions of each of these alternatives have an equal probability.' Keynes strenuously opposed the principle and devoted an entire chapter of his book in an attempt to refute it." (http://mathworld.wolfram.com/PrincipleofInsufficientReason.html, accessed August 8, 2015)

[46] See Exhibit 2 to Direct Testimony of Professor Robert Mendelsohn, June 1, 2015, p. 9.

[47] See Direct Testimony of Professor Robert Mendelsohn, June 1, 2015, p.12.

[48] Direct Testimony and Exhibits of Dr. Roger H. Bezdek, June 1, 2015; Direct Testimony and Exhibits of Professor William Happer, June 1, 2015; Direct Testimony and Exhibits of Professor Richard Lindzen June 1, 2015; Direct Testimony and Exhibits of Professor Robert Mendelsohn, June 1, 2015; Direct Testimony and Exhibits of Professor Roy Spencer, June 1, 2015.

[49] Martin Testimony, p. 24.

[50] Martin Testimony, pp. 22-23.

[51] Another source of potential upward bias in the federal SCC estimates occurs, I understand, because they do not properly incorporate potential environmental benefits of carbon dioxide; see Bezdek Testimony, p. 8, and Happer Testimony, p. 4.

31. Moreover, even established scientific consensus may turn out to be wrong. A recent example is the reversal in treatment guidelines with respect to hormone replacement therapy ("HRT") for postmenopausal women.

32. As of 1992, the published treatment guidelines of the American College of Physicians recommended for asymptomatic postmenopausal women, "based on the best available current data," that "All women, regardless of race, should consider preventive hormone therapy" and counseled that "Women who have coronary heart disease ["CHD"] or who are at increased risk for coronary heart disease are likely to benefit from hormone therapy."[52] At that time, the expectation for the potential of HRT to provide protection against CHD was based on "trials in nonhuman primates, and a large body of observational studies suggesting a 40% to 50% reduction in risk" of CHD among users of HRT.[53] Under the prevailing treatment guidelines, the "percentage of women aged 50 to 74 years taking hormone therapy increased from 33% to 42% between 1995 and 2001."[54]

33. The treatment guidelines for HRT changed abruptly in 2002 upon the publication of the principal results of the Women's Health Initiative's randomized controlled clinical trial of HRT, which was designed to study the health benefits and risks for predominately healthy women of the most commonly used HRT in the United States.[55] In May 2002 after an average follow-up duration of only 5.2 years of the planned 8.5 years, the trial's safety monitoring board halted the trial because the adverse event threshold for invasive breast cancer had been exceeded and tracking statistics indicated that risks of HRT were exceeding benefits.[56] In a complete reversal of prior guidelines, the published report on the study

[52] American College of Physicians, 1992, "Guidelines for counseling postmenopausal women about preventive hormone therapy," *Ann Intern Med*., 117(12):1038-1041.

[53] Rossouw JE, et. al. (Writing Group for the Women's Health Initiative Investigators), 2002, "Risks and benefits of estrogen plus progestin in healthy postmenopausal women: Principal results from the Women's Health Initiative randomized controlled trial," *JAMA*, 288:321–33.

[54] Hersh AL, Stefanick ML, Stafford RS, 2004, "National use of postmenopausal hormone therapy: annual trends and response to recent evidence," *JAMA*, 291(1):47-53.

[55] Rossouw JE, et al., op. cit. CHD was designated as the primary outcome for the WHI study, which enrolled 16,608 women during 1993-1998 with a planned duration of 8.5 years.

[56] The hazard ratio for CHD associated with the use of HRT was estimated from the trial at 1.29 (95% confidence interval 1.02-1.63).

concluded that HRT “should not be initiated or continued for primary prevention of CHD.”[57] By July 2003, HRT use by women aged 50 to 74 years had declined to 28%.[58] The prior treatment guideline, based on initial, indirect evidence (i.e., nonhuman primates and observational studies), had been revealed by later, more rigorous scientific evidence (i.e., randomized controlled clinical trial) to be doing more harm than good.

34. To the extent that IWG SCC modeling represents a current, prevailing consensus (even if only among IWG participants), I am aware of no rational basis for ruling out the possibility of future revision or even overturning of this consensus. This possibility amounts to an additional source of genuine uncertainty concerning inferences based on the IWG SCC calculations that is *not* accounted for in the IWG’s Monte Carlo simulations of ranges of uncertainty or, therefore, in Martin Figure 2 or Martin Table 2. In other words, the SCC calculated by the IWG is even more uncertain than is accounted for by the wide ranges of uncertainty shown in Martin Figure 2 and Martin Table 2.[59] Moreover, as in the HRT example, implementation of Mr. Martin’s proposed ECC range, which is based entirely on highly uncertain inferences from IWG modeling, risks doing more harm than good.

35. I note that even before considering the additional sources of uncertainty outlined above, several of the IWG’s alternative probabilistic forecasts shown in Martin Figure 2 are not “statistically significantly” positive, i.e., reliably distinguishable from zero by standard statistical criteria. Specifically, for 13 of the 15 distinct sets of IWG cost estimates calculated using the FUND IAM,[60] the 5th percentile falls below zero. Interpreting each of these 5th percentiles as a 95% lower confidence bound for the SCC, a value below zero implies that the corresponding SCC estimate is not “statistically significantly” greater than zero. This

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[57] Rossouw JE, et al., op. cit., p. 332.

[58] Hersh AL, Stefanick ML, Stafford RS, op. cit., p. 49.

[59] This additional source of uncertainty affects not only Mr. Martin’s proposal to the Commission in this proceeding, but also *any* inference that relies on the IWG SCC outputs, including the IWG’s own summary conclusions concerning the SCC.

[60] Representing 5 SESs × 3 discount rates.

same negative finding holds for 8 of the 15 sets of IWG cost estimates at the 90% level of confidence, and 15 of 15 at the 99% level of confidence.[61]

Mr. Martin's Unprincipled Treatment of the Choice of Discount Rates

36. Mr. Martin's implicit "equally likely" treatment of alternative discount rates is inappropriate because, as other experts have observed, the discount rate is not a model parameter whose true value is uncertain but, rather, reflects a decision-making tradeoff whose value the ultimate decision maker must choose, guided by economic theory and other normative considerations.[62]

Mr. Martin's Specious and Meaningless Application of the "Bootstrap" Method

37. Mr. Martin's "bootstrap" calculation[63] adds a gloss of statistical science to his proposal, but adds no substance. In the context of Mr. Martin's analysis in this proceeding, his bootstrap calculation is a complicated and computationally laborious way of obtaining an approximate answer to a question that can instead be answered simply and exactly without involving the bootstrap method. Employing the bootstrap method in this manner is analogous to estimating the number of cars in a parking lot by the laborious, approximate method of counting visible tires and dividing by four, instead of by the simple, exact method of just counting the cars. In either case the appearance of mathematical or arithmetical sophistication of the laborious, indirect method adds nothing to the mathematical validity or evidential weight of the resulting count.

38. This is so because, by definition, the bootstrap distribution of the 25^{th} percentile is simply the sampling distribution of the 25^{th} percentile calculated from samples[64] of size 150,000 from a given, fixed, discrete uniform distribution on 150,000 SCC values from IWG. The sample 25^{th} percentile is known to be a consistent estimator of the population 25^{th} percentile. Its sampling distribution is known to be asymptotically normal, centered at the population 25^{th} percentile. Thus, the exact value of the parameter Mr. Martin estimated in terms of a sample

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[61] This is so because 15 of 15 1^{st} percentile values fall below zero, and 8 of 15 10^{th} percentile values fall below zero.

[62] See, for example, Exhibit 2 to Direct Testimony of Professor Robert Mendelsohn, June 1, 2015, p. 16.

[63] Martin Testimony, p. 55.

[64] Bootstrap sampling is performed *with* replacement.

of size 10,000 from the bootstrap distribution of 25th percentile values was actually knowable *a priori*: it is simply the 25th percentile of the underlying set of 150,000 SCC values from IWG. Any deviation of Mr. Martin's "bootstrap estimate" from this population value must result solely from sampling error and finite sample bias—both of which are irrelevant in principle to Mr. Martin's purpose in calculating the percentile values.

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39. In connection with my anticipated testimony in this proceeding, I may use as exhibits various materials or documents that refer or relate to the matters discussed in this report. In addition, I reserve the right to use animations, demonstrative exhibits, enlargements of actual exhibits, and other information of any kind in order to convey my opinions.
40. I reserve the right to amend or supplement this report should additional information become available to me or for any other reason.
41. I hold each opinion expressed in this report to a reasonable degree of scientific certainty. These opinions are based on information, data, and analyses of the types typically and reasonably relied upon by experts in my fields of expertise. My opinions are based, in particular, on my education, knowledge, and experience in applied mathematics and statistics. I may do additional work. In particular, I understand that I may be asked to assess and respond to opinions offered by other witnesses, and, from the perspective of my areas of expertise, to review and respond to any additional reports or other supplementation that may be produced by other experts and to testimony and exhibits presented by the parties in this proceeding.

William E. Wecker
August 12, 2015

Materials Considered

Direct Testimony and Schedules of Mr. Nicholas F. Martin, June 1, 2015.

Direct Testimony and Exhibits of Dr. Roger H. Bezdek, June 1, 2015.

Direct Testimony and Exhibits of Professor William Happer, June 1, 2015.

Direct Testimony and Exhibits of Professor Richard Lindzen June 1, 2015.

Direct Testimony and Exhibits of Professor Robert Mendelsohn, June 1, 2015.

Direct Testimony and Exhibits of Professor Roy Spencer, June 1, 2015.

Direct Testimony and Exhibits of Anne E. Smith, Ph.D., June 1, 2015.

Draper, D., Gaver, D. P., et al., 1992, *Combining Information: Statistical Issues and Opportunities for Research*, National Academies Press.

Clemen, R. T., and Winkler, R. L., 1999, "Combining probability distributions from experts in risk analysis," *Risk Analysis*, 19, 187-203.

Clemen, Robert T., and Robert L. Winkler, 2007, "Aggregating probability distributions," in *Advances in decision analysis: From foundations to applications* (2007): 154-176.

Gneiting, T., and Ranjan, R., 2013, "Combining predictive distributions," *Electronic Journal of Statistics*, 7(1), 1747–1782.

"Decision Theory," Encyclopedia of Statistical Sciences, Wiley, 1982, Vol. 2, p. 277.

Berger, James O., 1993, Statistical Decision Theory and Bayesian Analysis, 2nd ed., Springer, 1993, and DeGroot, M. H., 2004, *Optimal Statistical Decisions*, Wiley-Interscience.

http://mathworld.wolfram.com/PrincipleofInsufficientReason.html, accessed August 8, 2015.

American College of Physicians, 1992, "Guidelines for counseling postmenopausal women about preventive hormone therapy," *Ann Intern Med*., 117(12):1038-1041.

Rossouw, J. E., et al. (Writing Group for the Women's Health Initiative Investigators), 2002, "Risks and benefits of estrogen plus progestin in healthy postmenopausal women: Principal results from the Women's Health Initiative randomized controlled trial," *JAMA*, 288:321–33.

Hersh, A. L., Stefanick, M. L., and Stafford, R. S., 2004, "National use of postmenopausal hormone therapy: annual trends and response to recent evidence," *JAMA*, 291(1):47-53.