Appendix A: Supplements to the Responses from Section 4 CSR-240-22.070

Risk Aversion Analysis

The content of this section concerns how to more formally simulate AmerenUE's risk aversion to large losses (or high PVRR values) and to determine if there is a reasonable level of risk aversion at which the NUC1600-Agg-LowNoWind would no longer be preferred. Within the discipline of decision analysis, which provides a theoretical framework upon which optimal decisions under uncertainty can be identified, is a phenomenon called risk preference. Central to the theory of risk preference is a concept known as the certainty equivalent (CE).[1] For example, consider two lotteries: (1) a 50:50 chance of winning $100 or losing $50, and (2) a 50:50 chance of winning $1 billion or losing $500 million. Most corporations would be willing to purchase a ticket in the first lottery up to the expected value of its outcomes, equal to $25. Situations like this, oftentimes when the stakes are low, describe what decision analysts define as risk neutrality, where the certainty equivalent of the lottery is exactly equal to the expected value of the lottery's uncertain outcomes. On the other hand, most corporations would not be willing to purchase a ticket equal the expected value of the second lottery's uncertain outcomes, $250 million, because of the risk of the large loss of $500 million. From this simple example, it is clear that statistical expectation does not unilaterally capture how most businesses approach uncertainty, especially when the stakes are large.[2] In the context of PVRR figures in the range of $40 billion dollars, AmerenUE is most likely risk averse, meaning that the certainty equivalent of a lottery is less than the expected value of its uncertain outcomes.

Because PVRR outcomes vary across probability tree endpoints, one can think of each alternative resource plan as an uncertain venture. The certainty equivalent, in this case, is the PVRR value that, if AmerenUE could have it with certainty, it would be indifferent between that and the uncertain venture. Importantly, the certainty equivalent can be used to rank resource

[1] The certainty equivalent is the certain amount that is equally preferred to a venture with uncertain outcomes, or lottery. When considering costs like the present value of revenue requirements, the preferred alternative will be the lottery with the lower certainty equivalent. Kirkwood, Craig W. *Notes on Attitude toward Risk Taking and the Exponential Utility Function*, January 1997, p. 2. Available at: http://www.public.asu.edu/~kirkwood/DAStuff/refs/risk.pdf.
[2] *Ibid*, p. 2.

plans relative to one another (lower certainty equivalents are preferred), and also to indicate the strength of this preference. How does one mathematically derive the certainty equivalent of each plan? It is directly dependent upon the form of what is called a utility function, which monotonically maps each PVRR value to a level of satisfaction, or utility. If AmerenUE is risk averse to extremely costly outcomes, the utility function should give greater and greater "disutility" to higher PVRR outcomes. As elucidated below, when in accordance with certain properties, the utility function can be completely characterized by a single parameter representing risk aversion.

If a decision-maker's preferences satisfy the five axioms of rational choice, then these preferences may be encoded into a unique utility function u(*x*) that maps each outcome *x* to a utility number u(*x*).[3] Two fundamental properties of utility functions are as follows. One, the utility of any venture is the expected utility of its uncertain outcomes. In the context of IRP resource plan selection, this is tantamount to asserting that the utility of an alternative resource plan is the expected utility of the PVRR outcomes across each of the 324 distinct end states created by the scenario and critical independent uncertainties. Two, if one venture (or resource plan) is preferred to another, then it must have a higher utility. For purposes of the IRP, any appropriate utility function will, in turn, be monotonically decreasing over the domain of PVRR values. Furthermore, risk aversion implies that extremely high PVRR values should be weighted more heavily, as AmerenUE wishes to avoid such negative outcomes. In other words, the utility of an alternative resource plan should decrease more rapidly at higher PVRR values. These desired characteristics of the utility function lead to a functional form similar to that presented graphically in Figure E-1. Under risk neutrality, the utility function is linear, stretching from the lowest PVRR value down to the highest PVRR value with constant slope. As the utility function incorporates greater risk aversion, it bows more and more outward to the right and assumes the concave downward shape shown.

[3] *Ibid*, pp. 17-19.

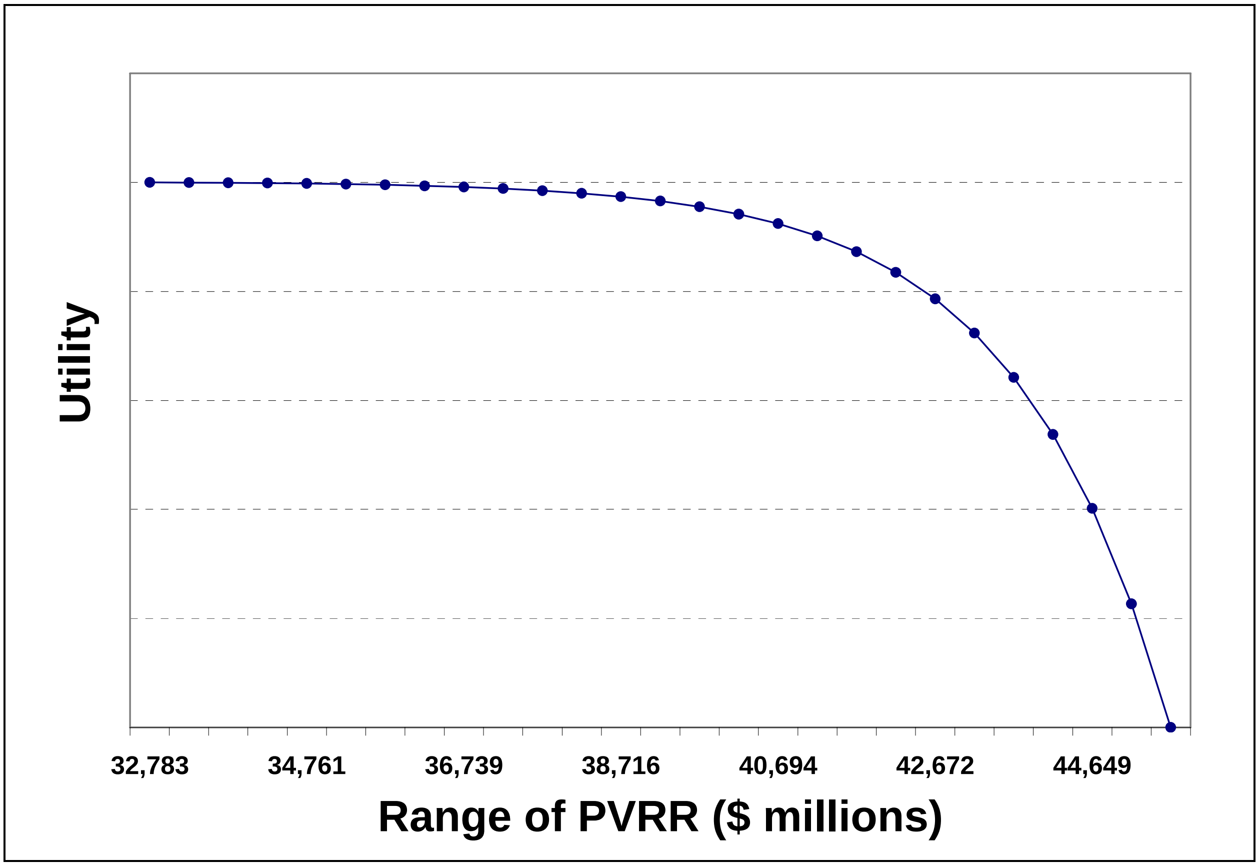

Figure E-1: Representative Utility Function that Incorporates Risk Aversion.

Consistent with standard decision analysis practice, an exponential utility function is an obvious candidate that assumes the shape in Figure E-1. If one restricts the form of the utility curve to the class of exponential functions, a sixth property in addition to the five axioms of rational choice must hold. Known as the delta property, it posits that if all outcomes of an uncertain proposition are changed by some specified amount, then the certainty equivalent of the uncertain proposition changes by that same amount.[4] By theorem, acceptance of this delta property implies a condition called constant absolute risk aversion (CARA), where risk preference is characterized by a single number, *R*, called the risk tolerance.[5] Lower and lower nonzero levels of risk tolerance denote a more risk averse, curved utility function. A convenient parameterization of such an exponential utility function would assign a utility of zero to the least

[4] *Ibid*, p. 4.
[5] *Ibid*, p. 5.

preferred level of the evaluation measure (highest PVRR) and a utility of one to the most preferred level (lowest PVRR). The following functional form[6] accomplishes this scaling:

$$U(x) = \{\exp[-(Max - x) / R] - 1\} / \{\exp[-(Max - Min) / R] - 1\},$$

where x represents the PVRR (in millions of dollars), *Max* is the highest PVRR outcome across all resource plans and all 324 end states,[7] *Min* is the lowest PVRR outcome, and $0 < R <$ infinity is the risk tolerance level. Using a simple identity,[8] one can then deduce the functional form of the certainty equivalent (CE):

$$CE = R * \ln \{EV [\exp (x / R)]\}.$$

This formula has three notable features. One, the certainty equivalent of a resource plan is only dependent upon the distribution of the PVRR values and the risk tolerance level, *R*. Two, as the risk tolerance level *R* decreases, the certainty equivalent decreases. Three, as the risk tolerance level *R* approaches infinity, the certainty equivalent of the resource plan approaches its expected PVRR value. Based on a utility function that weights higher PVRR values more heavily, this formulation of the certain equivalent is ideal for determining a "threshold" level of risk aversion above which a different plan is preferred to the one identified with risk neutrality (*i.e.*, NUC1600-Agg-LowNoWind).

There were two alternative resource plans that possessed the lowest certainty equivalent across a computable range of risk aversion: NUC1600-Agg-LowNoWind and Combine Cycle-Agg-LowNoWind. Figure E-2 plots the certainty equivalent of these two resource plans across a wide range of risk aversion coefficients, *C*.[9] As shown, the NUC1600-Agg-LowNoWind plan has a lower certainty equivalent for all values of the risk aversion coefficient less than C^*, beyond which the Combine Cycle-Agg-LowNoWind plan is preferred. Clearly, a "threshold" or "crossover" risk aversion level exists at which the preferred plan under risk neutrality is no longer preferred. The question that then arises is whether or not this level of risk aversion is

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[6] Kirkwood, Craig W. *Notes on Attitude toward Risk Taking and the Exponential Utility Function*, p. 6. Available at: http://www.public.asu.edu/~kirkwood/DAStuff/refs/risk.pdf.

[7] See the response to section 4 CSR 240-22.070 (5) (A) for an explanation of what the 324 end states denote. The final probability tree contained nine scenario branches and 36 critical independent uncertainty branches (3 capital cost settings, 3 interest rate settings, 2 off-systems sales settings, and 2 renewable production tax credit settings), resulting in 9 x 3 x 3 x 2 x 2 = 324 outcomes or end states for each alternative resource plan.

[8] Kirkwood, Craig W. *Notes on Attitude toward Risk Taking and the Exponential Utility Function*, p. 7. Available at: http://www.public.asu.edu/~kirkwood/DAStuff/refs/risk.pdf. The utility of the certainty equivalent (CE) is equal to the expected value of the uncertain outcome x, *i.e.*, U (CE) = EV (x).

[9] Recall that the risk aversion coefficient is the reciprocal of risk tolerance. As will be explained, risk tolerance has a more intuitive interpretation, but, for purposes of graphing certainty equivalents, the risk aversion coefficient is more appropriate.

reasonable for the party that is truly at risk – AmerenUE ratepayers. The crossover risk aversion coefficient implies a risk tolerance of $448 million, which is roughly equivalent to 1.5% of the AmerenUE rate base when annualized over the course of the 20-year planning horizon.

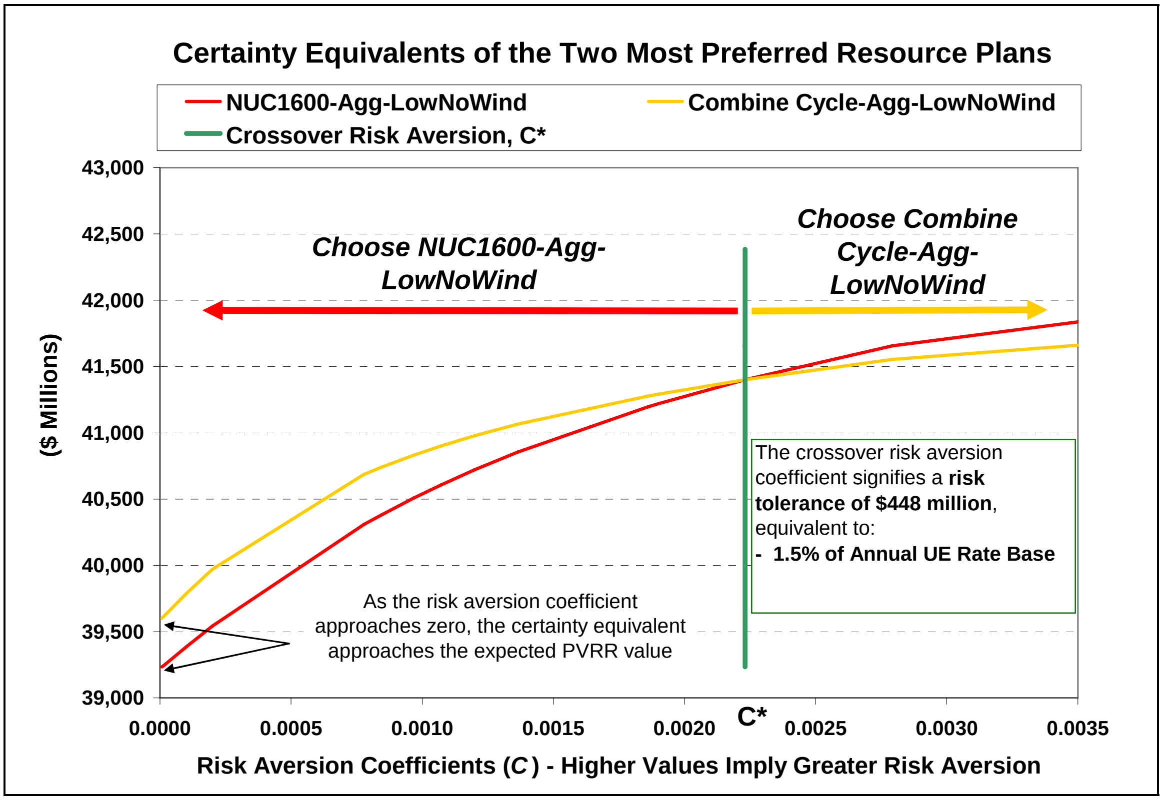

Figure E-2: Identifying the "Threshold" Risk Aversion Level by Comparing the Certainty Equivalents of the NUC1600-Agg-LowNoWind and Combine Cycle-Agg-LowNoWind Alternative Resource Plans.

Despite having framed the crossover risk tolerance level in terms of AmerenUE's rate base, there is little basis, thus far, upon which to decide if such risk aversion is within reason. To do this, the general intuition behind risk tolerance needs to be flushed out. Imagine an uncertain venture with an equal probability of decreasing the PVRR of a resource plan by an amount equal to *R* or increasing the PVRR by an amount equal to (1/2) x *R*. It can be shown that the value of *R* that would make the decision maker indifferent between taking this risk and not taking this risk is the risk tolerance level.[10] Figure E-3 provides an illustrative example.

[10] Kirkwood, Craig W. *Notes on Attitude toward Risk Taking and the Exponential Utility Function*, p. 8. Available at: http://www.public.asu.edu/~kirkwood/DAStuff/refs/risk.pdf. An equivalent statements is that the risk tolerance is equal to the value *R* such that an uncertain proposition with equal chances of winning *R* or losing (1/2) x *R* has a certainty equivalent of zero.

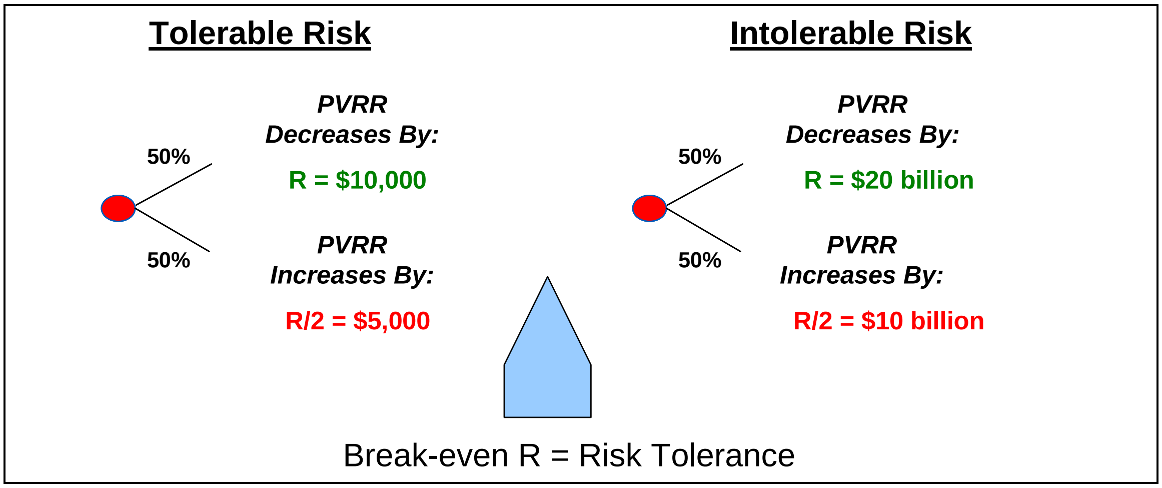

Figure E-3: How to Elicit Risk Tolerance.

Whether AmerenUE decision makers will accept a 50:50 risk of either reducing the PVRR of a resource plan by an amount *R* or raising the PVRR by half that amount naturally depends upon the magnitude of *R*. When *R* is small, the downside risk, equal to (1/2) x *R*, is small. For instance, AmerenUE decision-makers, on behalf of AmerenUE ratepayers, are not so risk averse that they will not risk increasing the PVRR by $5,000 if there is an equal chance of decreasing the PVRR by $10,000. This 50:50 proposition is a tolerable risk. However, if one goes to the other extreme in Figure E-3, where *R* is equal to $20 billion, it is highly unlikely that AmerenUE would risk increasing the PVRR by $10 billion (nearly equal to the total spread from the maximum and minimum PVRR values across the top 18 resource plans) at an equal chance of decreasing the PVRR by $20 billion. This proposition is therefore an intolerable risk. To elicit the true risk tolerance level, one should zero in on the break-even level of *R*, somewhere between $10,000 and $20 billion, at which the decision-maker is indifferent to taking the risk. For values of *R* greater than this break-even value, the decision-maker would not be willing to take the risk, and for values of *R* less than this break-even value, the decision-maker would be willing to take the risk.

The pivotal question then becomes whether or not the threshold risk tolerance level *R**, equal to $448 million, is less than or greater than this break-even value (recall that this risk tolerance level is tantamount to a change in annual AmerenUE rates of 1.5%). Because it is AmerenUE ratepayers who are really at risk (based on the premise of perfect ratemaking), it is useful to transform the example presented in Figure E-3 in terms of impacts on annual

AmerenUE rates. Consider an uncertain venture with equal probability of lowering annual AmerenUE rates by 1.5% or of raising annual AmerenUE rates by 0.75%. Assume that the average monthly household electricity bill for AmerenUE customers is $50. Are AmerenUE ratepayers willing to risk a $0.38 increase in their monthly electricity bill at an equal chance of a $0.75 decrease? It is AmerenUE's judgment that such a risk is acceptable to the overwhelming majority of AmerenUE ratepayers. This pronouncement has a powerful implication. It means that the crossover R^* represents a level of risk aversion that is beyond the bounds that can be reasonably attributed to AmerenUE ratepayers, and that the Combine Cycle-Agg-LowNoWind option would only be preferred at unreasonably high levels of risk aversion. As such, this risk aversion analysis demonstrates that although there are two alternative resource plans that might be selected under any level of risk aversion (NUC1600-Agg-LowNoWind and Combine Cycle-Agg-LowNoWind), the NUC1600-Agg-LowNoWind resource plan is always preferred under reasonable levels of risk aversion.

Expected PVRRs Given Uncertainty, and Certainty in Each Critical Variable:	***All Uncertainties***	***CO_2 Policy***				***Natural Gas Prices***		***Load Growth***		***Capital Costs***			***Interest Rates***			***Off-System Sales***		***NRPTC***	
Build Plan	**(Without Perfect Info)**	**High Price**	**Moderate Price**	**Mandates**	**BAU**	**High**	**Base**	**TransDem**	**Base**	**High**	**Base**	**Low**	**High**	**Base**	**Low**	**Base**	**Low**	**Base**	**None**
NUC1200-Agg-Moderate	39,457	40,537	37,760	36,772	36,055	39,278	39,636	38,637	39,519	40,316	39,425	38,858	40,588	39,456	38,328	38,704	40,210	39,257	39,657
NUC1600-Agg-Moderate	39,404	40,388	37,844	36,978	36,273	39,200	39,608	38,578	39,466	40,432	39,382	38,548	40,603	39,399	38,213	38,555	40,253	39,204	39,604
Combine Cycle-Agg-Moderate	39,753	41,101	37,683	36,303	35,601	39,683	39,822	39,027	39,807	40,187	39,736	39,449	40,660	39,755	38,839	39,226	40,279	39,552	39,953
Pumped Storage-Agg-Moderate	39,767	41,115	37,697	36,315	35,600	39,705	39,829	39,016	39,823	40,237	39,747	39,456	40,688	39,771	38,836	39,223	40,310	39,566	39,967
Coal850W/OCCS-Agg-Moderate	39,882	41,268	37,773	36,303	35,625	39,797	39,966	39,088	39,942	40,428	39,860	39,514	40,839	39,883	38,922	39,247	40,517	39,682	40,082
Coal425W/OCCS-Agg-Moderate	39,892	41,275	37,798	36,303	35,692	39,809	39,975	39,134	39,949	40,397	39,871	39,554	40,827	39,895	38,951	39,322	40,463	39,692	40,093
NUC1200-Agg-High	39,945	40,996	38,552	36,842	37,054	39,714	40,175	39,114	40,007	41,070	39,924	38,983	41,140	39,957	38,725	39,038	40,851	39,484	40,406
NUC1600-Agg-High	40,049	41,018	38,751	37,210	37,374	39,781	40,317	39,230	40,110	41,372	40,020	38,956	41,340	40,050	38,756	39,016	41,082	39,588	40,510
Simple Cycle-Agg-High	40,256	41,587	38,473	36,362	36,642	40,109	40,404	39,488	40,314	40,932	40,240	39,712	41,235	40,261	39,269	39,612	40,901	39,796	40,717
NUC1200-Agg-Wind	40,026	41,085	38,425	37,275	36,804	39,819	40,233	39,206	40,088	41,164	39,986	39,211	41,212	40,030	38,834	39,220	40,833	39,611	40,441
NUC1600-Agg-Wind	40,020	40,991	38,554	37,491	37,065	39,790	40,251	39,201	40,082	41,287	39,992	38,984	41,276	40,020	38,765	39,095	40,946	39,606	40,435
NUC1200-Agg-LowW/Wind	39,611	40,668	37,626	37,591	35,746	39,474	39,747	38,817	39,671	40,544	39,546	39,192	40,708	39,613	38,508	38,978	40,243	39,515	39,707
NUC1600-Agg-LowW/Wind	39,582	40,544	37,733	37,825	35,994	39,415	39,750	38,771	39,643	40,658	39,516	39,034	40,789	39,575	38,389	38,860	40,305	39,487	39,678
NUC1200-Agg-no	39,468	40,565	37,433	37,320	35,492	39,353	39,582	38,681	39,527	40,127	39,447	38,974	40,534	39,468	38,400	38,869	40,066	39,468	39,468
NUC1600-Agg-no	39,414	40,414	37,512	37,551	35,710	39,267	39,562	38,606	39,475	40,223	39,391	38,797	40,546	39,419	38,274	38,732	40,097	39,414	39,414
Coal425W/OCCS-Agg-no	39,758	41,139	37,323	36,819	34,997	39,742	39,775	39,047	39,812	40,022	39,743	39,616	40,634	39,762	38,876	39,305	40,212	39,758	39,758
NUC1600-Agg-LowNoWind	39,221	40,191	37,478	37,223	35,788	39,050	39,392	38,400	39,283	40,042	39,203	38,543	40,383	39,211	38,080	38,463	39,979	39,179	39,263
Combine Cycle-Agg-LowNoWind	39,584	40,927	37,319	36,532	35,148	39,539	39,629	38,878	39,637	39,884	39,567	39,415	40,449	39,588	38,711	39,134	40,033	39,542	39,626
Build Plan with Minimum Expected PVRR	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	Combine Cycle-Agg-LowNoWind	Combine Cycle-Agg-Moderate	Coal425W/OCCS-Agg-no	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	Combine Cycle-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind	NUC1600-Agg-LowNoWind
	PVRR Without Perfect Info:																		
Minimum Expected PVRR	**39,221**	**40,191**	**37,319**	**36,303**	**34,997**	**39,050**	**39,392**	**38,400**	**39,283**	**39,884**	**39,203**	**38,543**	**40,383**	**39,211**	**38,080**	**38,463**	**39,979**	**39,179**	**39,263**
Subjective Probability		65.7%	21.8%	12.0%	0.5%	50%	50%	7%	93%	10%	80%	10%	25%	50%	25%	50%	50%	50%	50%
Expected PVRR with Perfect Info		**39,072**				**39,221**		**39,221**		**39,205**			**39,221**			**39,221**		**39,221**	
EVPI		**148.8**				**0**		**0**		**15.8**			**0**			**0**		**0**	

Figure E-4: Expected Value of Perfect Information under Risk Neutrality ($ Millions).