Illinois Institute of Technology - Stuart School of Business

MSF 524

Fall 2013 - Friday 6:00 PM Section

Term Project

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Due: December 7th, 2013

1) Executive Summary

Several power plant investment opportunities are evaluated in order to help an energy company make an investment decision. The opportunities are modeled using a real option of a future simple exchange option. Calculations are conducted using Monte-Carlo simulation in Matlab with the use of several variance reduction techniques. Real option premiums and exercise frequencies are used to compare the opportunities. It is found that a power plant in Alaska is the best candidate based on the real option premiums and their relative risk. However, a surface-level investigation into other factors reveals that the real option premiums alone are not enough for the company to make a reliable investment decision.

2) Introduction

An energy company has 30 power plant investment opportunities available. They are interested in evaluating the amount of money the company could make per MWh for the life of the power plant from each of the opportunities. Each opportunity would be located in one of fifteen states, and involves building either a coal power plant or a natural gas power plant to generate electricity. Once a company has built a power plant, it will be able to sell electricity to the market at the market price for the corresponding state.

In evaluating the opportunities, we follow the methods proposed by Kang and Letourneau (2013). We consider a company's real option of building a power plant that will begin generating electricity in one year (the time when the power plant is built and ready to generate). We also assume that the power plant has the ability to generate electricity continuously for 30 years. In order to model the real option, we use a compound exchange option (hereafter CEO)[1]. The CEO is essentially a European call option with a target date of one year in the future. The underlying asset for the CEO is the

[1] Carr, P.(1988).

simple exchange option (hereafter SEO) to be able to sell generated electricity for the market price of electricity. The strike price of the CEO is the capital cost of the power plant *per MWh*. The target date of the SEO is the "average time weighted by the time value of money"[2].

In this study, we will first confirm methods to evaluate the CEO premiums for every opportunity. This will be done by determining the validity of the equation for d_1 in Carr (1988), then using the appropriate equation to mimic calculations conducted in Kang and Letourneau (2013). We will use a graphical method to confirm our calculation, thus validating our method. Lastly, we will evaluate the CEO premiums for all 30 opportunities under 4 different market scenarios, and make an appropriate recommendation to the business.

3) <u>Methodology</u>

The first task of this study is to determine the validity of the equation for d_1 in Carr (1988). In order to achieve this we must first calculate the CEO premiums using a Monte-Carlo simulation. Then we calculate both the "typo" equation and "corrected" equation. The solution calculated from the Monte-Carlo simulation will then allow us to determine the correctness of the d_1 equation in Carr (1988). The last step in this task is to compare the results of the Monte-Carlo simulation with the results of both the "typo" and the "corrected" equations. We should see a match between our Monte-Carlo simulation results and our "corrected" analytical results, and a disparity with our "typo" results.

<u>Monte-Carlo Simulation</u>

In order to achieve this comparison with Matlab, three functions were written which were then called through a script. The first function returned the price of the CEO calculated using Monte-Carlo simulation (hereafter **CEO_MC()**). The level of precision was required to be plus or minus one cent (+/-

[2] Kang, S. B. and Letourneau, P. (2013).

$0.01). Therefore, several variance reduction techniques were implemented in order to increase the calculation speed of CEO_MC().

Outside of the function, the number of required iterations to control absolute error was calculated. This allowed us to use the least amount of iterations while still controlling error. To achieve this, CEO_MC() was run with a relatively small number of trial iterations. Then the required iterations were calculated using the variance of the CEO in the trial run, a standard normal z-coefficient, and the maximum absolute error using the equation below:

$$N = floor\left(\frac{S^2(N_{trial})(Z_{1-\frac{\alpha}{2}})^2}{2\beta^2}\right)$$

where β is the allowable absolute error of plus or minus one cent (+/- $0.01), α is 0.05, and “floor” is a function that rounds down to the nearest whole number. There is a coefficient of one-half applied to the function to account for the fact the number of iterations will be doubled (to a total of 2N) when we implement antithetic variables.

The two variance reduction techniques used within CEO_MC() were antithetic variables and one control variate. Antithetic variables were implemented by first simulating Brownian motion components to calculate the first half of the sample points, and then using the opposite (negative) of the components to calculate the second half of the sample points.

In order to find an effective control variate, several candidates were tested by checking the correlation of the simulated control variate with the simulated CEO. An additional consideration was to ensure that a theoretical calculation could be obtained from the control variate. It was found that SEO(V, D, Tc) was heavily correlated with our CEO = EuroCall(SEO(V, D, Ts), qD, Tc). An analytical closed-form solution for SEO(V, D, Tc) is also obtainable. Therefore, SEO(V, D, Tc) was used as the control variate. The strong correlation meant that the implementation of this control variate drastically decreased the variance in our CEO simulated points, thus decreasing the required iterations to control the absolute error and increasing calculation performance.

The simulated SEO(V, D, Tc) is calculated by computing the discounted simulated payoffs of exchanging D for V at time Tc. The theoretical SEO(V, D, Tc) is calculated by adapting the Margrabe formula in the special case where neither asset has a dividend yield. Note that the Margrabe formula used to calculate the theoretical control variate uses the same "corrected" equation for d_1 which is also present in the equation in question. Since we are using this d_1 as part of a variance reduction technique, this method does not violate our testing conditions when testing the "typo" equation. The simulated and theoretical formulas for SEO(V, D, Tc) are:

$$SEO(V,D,Tc)_{sim} = e^{-rT_c} * \max(V_{T_c} - D_{T_c}, 0),$$

and

$$SEO(V,D,Tc)_{theo} = V_0 * StdNormCDF(d_1) - D_0 * StdNormCDF(d_2).$$

where V_{T_c} and D_{T_c} are simulated values of V and D at time Tc, StdNormCDF(z) is a function for the value of the standard normal cumulative distribution function at z. d_1, d_2, and sigma-p are defined as follows:

$$d_1 = \frac{\ln\left(\frac{V}{D}\right) + \frac{\sigma_P^2 T_c}{2}}{\sigma_P\sqrt{T_c}} \quad , \quad d_2 = \frac{\ln\left(\frac{V}{D}\right) - \frac{\sigma_P^2 T_c}{2}}{\sigma_P\sqrt{T_c}} \quad ,$$

and

$$\sigma_P = \sqrt{\sigma_V^2 + \sigma_D^2 - 2\rho_{V,D}\sigma_V\, \sigma_D} \quad .$$

Despite the fact that there may be more effective control variates that can further reduce the variance of this CEO calculation, using SEO(V, D, Tc) provides adequate variance control and exceeds the calculation speed requirements for the purpose of this study.

Analytical Solutions using "Typo" and "Corrected" Equations

The second and third functions were used to calculate both versions of the analytical solution. Since d_1 components must be calculated several times to determine the analytical solution, the second function is for d_1 (hereafter **d1()**). This function was written with a special Boolean input to determine whether to use the "typo" or "corrected" versions of d_1 such that

$$d1(y,\sigma,\tau,typo) = \frac{\ln(y) + \sigma^2\tau}{\sigma\sqrt{\tau}} \quad , \quad d1(y,\sigma,\tau,corrected) = \frac{\ln(y) + 0.5 * \sigma^2\tau}{\sigma\sqrt{\tau}}$$

The third, and the last, function written is the analytical solution for the CEO, CEO_Analytic() . This function implements the analytical solution of the CEO found in equation 27 of Carr (1988). To implement this equation, the function first calculates P* by solving for P in equation 26 of Carr (1988), shown below:

$$P * StdNormCDF\big(d1(P,\sigma_P,T_s - T_c,\_)\big) - StdNormCDF\big(d2(P,\sigma_P,T_s - T_c,\_)\big) = q$$

where q is given, "__" represents whether we are using "typo" or "corrected", and d2 is

$$d2(y,\sigma,\tau,\_) = d1(y,\sigma,\tau,\_) - \sigma\sqrt{\tau} \ .$$

Once P* is calculated we calculate the return of CEO_Analytic() using equation 27 of Carr (1988), shown below:

$$CEO = V_0 * StdBivNormCDF(d1(P/P^*,\sigma_P,Tc,\_),d1(P,\sigma_P,Ts,\_))$$

$$-D_0 * StdBivNormCDF(d2(P/P^*,\sigma_P,Tc,\_),d2(P,\sigma_P,Ts,\_))$$

$$-q * D_0 * StdNormCDF(d2(P/P^*,\sigma_P,Tc,\_)).$$

where StdBivNormCDF(z1, z2) is a function for the value of the standard bivariate normal cumulative distribution function at z1 and z2.

<u>Confirmation of Monte-Carlo Simulation Method</u>

Using the illustrated methods, a numerical comparison is drawn between the simulated solution and both the "corrected" and the "typo" analytical solutions. It was shown that the "typo" solution was incorrect. Moreover, the comparison confirms the accuracy of the Monte-Carlo simulation method for calculating CEO premiums to evaluate different investment opportunities. Details about the numerical comparison are in the Appendix of this document.

<u>Evaluating Power Plant Investment Opportunities</u>

The CEO premiums and exercise frequencies of 30 power plant investment opportunities are evaluated and compared in order to provide an investment recommendation to the business. In this process of evaluation, several scenarios are evaluated separately for each opportunity to allow for unbiased comparison. For example, while opportunity A may be optimal in scenario X, it may present to be the worst in scenarios Y and Z.

It is important to highlight the hypothetical nature of the situation and thus we do not know the true probabilities of each scenario. As such, we assume that all scenarios have an equal likelihood of occurring. Based on this assumption, we can now fairly evaluate opportunities against each other by comparing their values averaged across all scenarios. The four scenarios being used for the purpose of this investigation are "Base Case", "No Emission Cost Case", "High Emission Cost Case", and "High Capital Cost Case". As stated, we evaluate the value of each of the thirty opportunities within each of the four scenarios.

To conduct these evaluations, we use the previously described function CEO_MC(). However, we implement one change to the calculation in order to fairly evaluate the opportunities. The strike price of the SEO at time Tc is set as a constant rather than as a function of the cost of generation. To implement this, a Boolean variable is used in CEO_MC() to toggle the constancy of the strike price when calculating the simulated CEO. As with the previous use of CEO_MC(), the correlation between the CEO (with constant K) and the control variate is checked to ensure variance reduction.

Once the average premium and exercise frequency for all opportunity-scenario points are evaluated, the opportunities are compared.

4) Numerical Results

In comparing the numerical results, we are most interested in the option premiums. Figure 1 represents what the business can expect to benefit by per MWh following a specific investment. We see in this figure that the investment opportunity with the highest expected CEO premium is to build a coal plant in Alaska. The next highest CEO premiums are for the opportunities to build a natural gas plant in Alaska, a coal plant in Colorado, and a natural gas plant in Colorado (respectively). These results are not surprising considering the cost of electricity is the highest in Alaska and second highest in Colorado.

We are also interested in comparing exercise frequencies of the CEO's. We see in Figure 2 that Alaska also has the highest exercise frequency for all coal plants as well as all natural gas plants. As expected, Colorado is once again a close second. It is worth noting that the exercise frequencies for natural gas plants are always higher than those of the coal plants for every state.

In Figure 3, we consider the standard deviations of the CEO premiums across the four scenarios to draw a simple comparison of risk across the opportunities. We observe that the CEO premiums of a coal plant in Alaska and a coal plant in Colorado have the highest standard deviations. However, since different opportunities offer varying levels of CEO premiums, considering the standard deviation alone could be a misleading measure of risk. Furthermore, an opportunity with high CEO premiums will tend to have higher standard deviations for CEO premiums further confirming that standard deviation consideration alone is an unsuitable measure of risk.

Therefore, we use Figure 4 to show the coefficients of variation across the different opportunities. The coefficients of variation, standardized by the opportunities' mean CEO premiums, offer a better comparison of risk from one opportunity to another. This is due to the fact that the coefficient of variation is a measure of risk relative to the magnitude of the CEO premium. We observe from Figure 4 that Alaska offers the lowest coefficients of variation for CEO premiums for both coal and natural gas plants.

5) <u>Discussion</u>

Figures 1 – 4 show that Alaska offers the highest CEO premiums, highest exercise frequencies, and lowest *relative* risk for both coal and gas plant opportunities. Colorado is a close second in all of the above-mentioned statistics. By contrast, Texas offers the lowest CEO premiums, lowest exercise frequencies, and highest relative risk for both coal and gas plants. Even though this study is conducted under a hypothetical situation, these results may be due in part to an over-saturated energy market in Texas and a relatively low amount of generation in Alaska. This current situation is shown in Figure 5.

Despite what our study indicates, considering the fact that companies still generate a large amount of electricity out of Texas allows us to hypothesize that there may be other factors operating in companies' investment decisions. Such factors may include the level of state consumption and the cost (and ability) to export to another state. According to the U.S. Energy Information Administration (hereafter EIA), "Alaska is not electrically connected to the Lower 48 states"[3]. This lack of infrastructure connection could completely negate the benefit predicted from a high CEO premium for the business if there is not enough consumption already present in Alaska. In addition, the EIA explains that "Alaska's electricity infrastructure differs from that of the lower 48 States in that most consumers are not linked to large interconnected grids through transmission and distribution lines"[4]. From this we can infer that despite having high CEO premiums in our study, an investment opportunity in Alaska might not be optimal.

6) Conclusion

From an economic standpoint, it is resonable that a power plant investment opportunity in Alaska would produce a high benefit on the per MWh basis. Moreover, based on the distribution of CEO premiums, a less risk-averse investor should choose a coal plant in Alaska whereas a more risk-averse investor should choose a natural gas plant in Alaska[5]. However, the business should consider other factors before making a decision in order to ensure an optimal return. Furthermore, the business should analyze the potential sales volume for all opportunities. The business should also investigate, at minimum, the infrastructure of the location, the cost to reach its customers, and the potential price competition from other companies in or outside the region. In summary, the calculation of the CEO premiums provides a confirmation that benefits *could* be gained from investing in a certain opportunity. However, it is imperative to keep in mind that the premium is one of many factors that should be considered before going forward with a power plant investment decision.

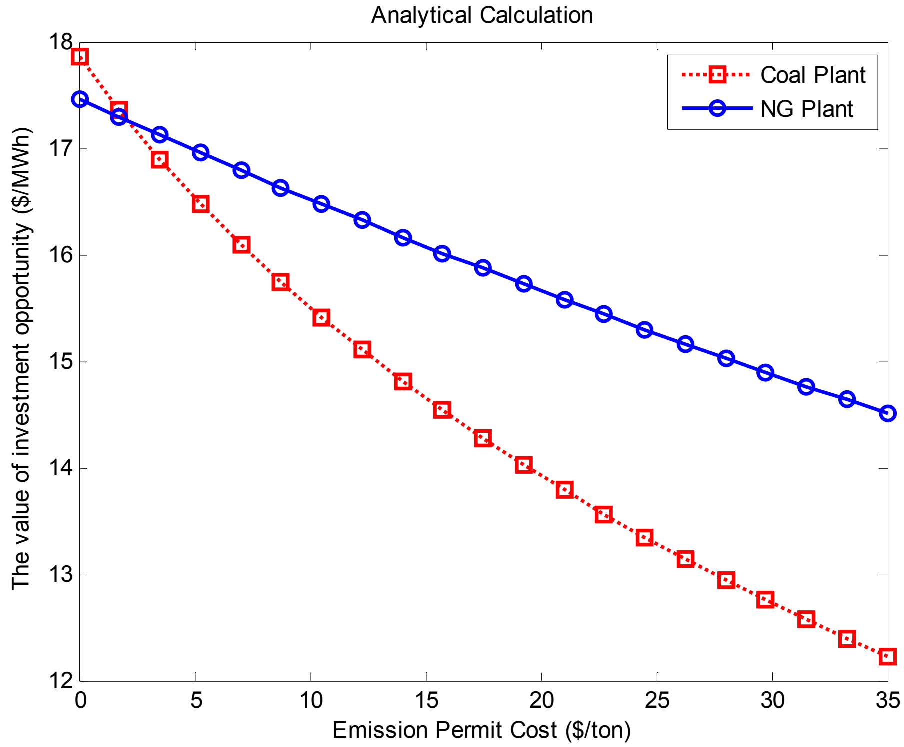
[3] U.S. Energy Information Administration. November 27, 2012.
[4] U.S. Energy Information Administration. July, 2012.
[5] This conclusion is drawn on the assumption that all other unmentioned factors are held constant across states.

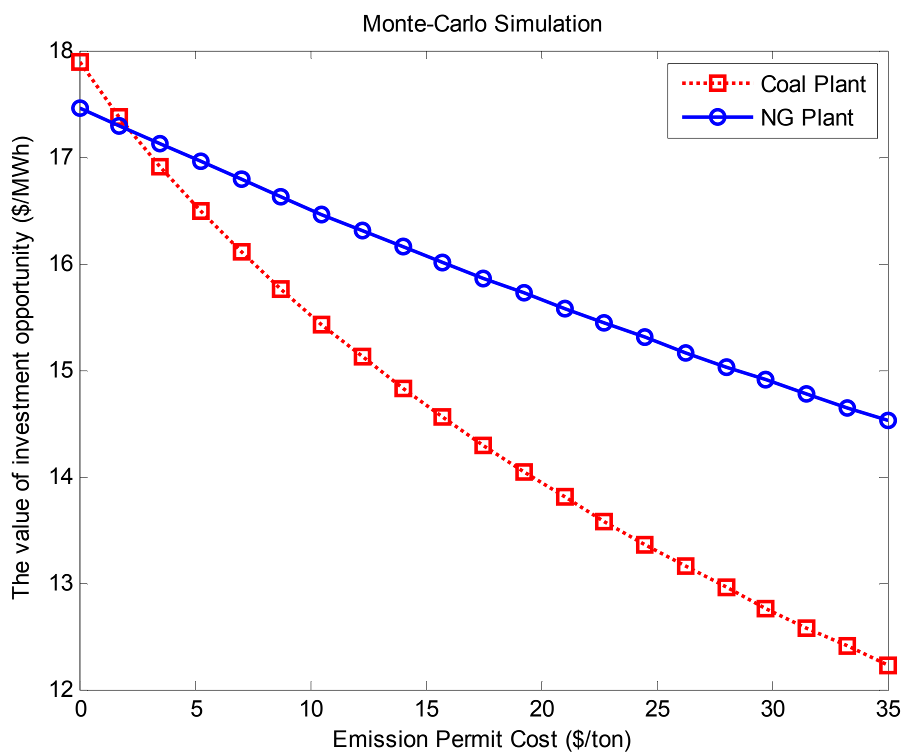
7) Appendix (Matlab outputs for Parts A, B, and C)

Part A Results – Comparison between Carr (1988) "typo" and "corrected" equations for d_1

```
CEO Calculated with Cond MC Simulation: $17.463526
         Confidence Interval          : $17.4554 to $17.4716
         Relative Error               : $-0.0081 to $+0.0081
         Relative Error Percentage    :  -0.046% to  +0.046%
CEO Calculated with Corrected Equation: $17.459410
CEO Calculated with Typo Equation     : $13.402568
```

Part B Results - Kang and Letourneau (2013) Figure 2 Replication





Part C Results – Power Plant Investment Opportunity Evaluation

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====================================================================
CEO Prices and Exercise Frequencies by State and Plant Type
====================================================================
State         Pant Type   Scenario                 Price($/MWh)  Freq
====================================================================
California    Coal Plant  Base Case                       12.85  45.3%
California    Coal Plant  No Emission Cost Case           18.72  60.1%
California    Coal Plant  High Emission Cost Case         10.21  38.0%
California    Coal Plant  High Capital Cost Case           3.97  12.8%
                          ------------------------------------------
                                State-Plant Mean Price  11.44
                                State-Plant Mean Freq          39.0%
--------------------------------------------------------------------
California    NG Plant    Base Case                       15.48  67.5%
California    NG Plant    No Emission Cost Case           18.45  73.8%
California    NG Plant    High Emission Cost Case         13.24  62.1%
California    NG Plant    High Capital Cost Case           6.95  29.5%
                          ------------------------------------------
                                State-Plant Mean Price  13.53
                                State-Plant Mean Freq          58.2%
--------------------------------------------------------------------
New York      Coal Plant  Base Case                       18.33  55.1%
New York      Coal Plant  No Emission Cost Case           25.48  69.3%
New York      Coal Plant  High Emission Cost Case         14.93  47.7%
New York      Coal Plant  High Capital Cost Case           6.59  18.7%
                          ------------------------------------------
                                State-Plant Mean Price  16.33
                                State-Plant Mean Freq          47.7%
--------------------------------------------------------------------
New York      NG Plant    Base Case                       19.80  74.3%
New York      NG Plant    No Emission Cost Case           22.81  79.1%
New York      NG Plant    High Emission Cost Case         17.43  69.9%
New York      NG Plant    High Capital Cost Case           9.86  36.9%
                          ------------------------------------------
                                State-Plant Mean Price  17.48
                                State-Plant Mean Freq          65.0%
--------------------------------------------------------------------
Idaho         Coal Plant  Base Case                        7.16  31.2%
Idaho         Coal Plant  No Emission Cost Case           11.01  44.5%
Idaho         Coal Plant  High Emission Cost Case          5.49  25.1%
Idaho         Coal Plant  High Capital Cost Case           1.75   6.6%
                          ------------------------------------------
                                State-Plant Mean Price   6.35
                                State-Plant Mean Freq          26.9%
```

```
---------------------------------------------------------------------
Idaho         NG Plant    Base Case                     9.64  53.7%
Idaho         NG Plant    No Emission Cost Case        12.09  61.5%
Idaho         NG Plant    High Emission Cost Case       7.91  47.3%
Idaho         NG Plant    High Capital Cost Case        3.58  18.4%
                          ------------------------------------------
                                State-Plant Mean Price   8.31
                                State-Plant Mean Freq           45.2%
---------------------------------------------------------------------
Illinois      Coal Plant  Base Case                     8.85  36.0%
Illinois      Coal Plant  No Emission Cost Case        13.55  50.6%
Illinois      Coal Plant  High Emission Cost Case       6.84  29.2%
Illinois      Coal Plant  High Capital Cost Case        2.35   8.4%
                          ------------------------------------------
                                State-Plant Mean Price   7.90
                                State-Plant Mean Freq           31.1%
---------------------------------------------------------------------
Illinois      NG Plant    Base Case                    11.21  58.0%
Illinois      NG Plant    No Emission Cost Case        13.79  65.3%
Illinois      NG Plant    High Emission Cost Case       9.35  51.9%
Illinois      NG Plant    High Capital Cost Case        4.43  21.4%
                          ------------------------------------------
                                State-Plant Mean Price   9.69
                                State-Plant Mean Freq           49.2%
---------------------------------------------------------------------
Alaska        Coal Plant  Base Case                    37.98  76.2%
Alaska        Coal Plant  No Emission Cost Case        47.03  84.9%
Alaska        Coal Plant  High Emission Cost Case      32.84  70.3%
Alaska        Coal Plant  High Capital Cost Case       18.64  38.3%
                          ------------------------------------------
                                State-Plant Mean Price  34.12
                                State-Plant Mean Freq           67.4%
---------------------------------------------------------------------
Alaska        NG Plant    Base Case                    31.67  84.9%
Alaska        NG Plant    No Emission Cost Case        34.25  87.1%
Alaska        NG Plant    High Emission Cost Case      29.42  82.8%
Alaska        NG Plant    High Capital Cost Case       19.03  53.0%
                          ------------------------------------------
                                State-Plant Mean Price  28.59
                                State-Plant Mean Freq           76.9%
---------------------------------------------------------------------
Lousiana      Coal Plant  Base Case                    11.43  42.2%
Lousiana      Coal Plant  No Emission Cost Case        16.90  57.0%
Lousiana      Coal Plant  High Emission Cost Case       9.00  35.0%
Lousiana      Coal Plant  High Capital Cost Case        3.36  11.2%
                          ------------------------------------------
                                State-Plant Mean Price  10.17
                                State-Plant Mean Freq           36.4%
```

Lousiana	NG Plant	Base Case	14.83	66.6%
Lousiana	NG Plant	No Emission Cost Case	18.03	73.6%
Lousiana	NG Plant	High Emission Cost Case	12.51	60.6%
Lousiana	NG Plant	High Capital Cost Case	6.51	28.4%
		State-Plant Mean Price	12.97	
		State-Plant Mean Freq		57.3%
Texas	Coal Plant	Base Case	6.80	30.2%
Texas	Coal Plant	No Emission Cost Case	10.77	44.4%
Texas	Coal Plant	High Emission Cost Case	5.16	24.0%
Texas	Coal Plant	High Capital Cost Case	1.62	6.3%
		State-Plant Mean Price	6.09	
		State-Plant Mean Freq		26.2%
Texas	NG Plant	Base Case	9.22	52.5%
Texas	NG Plant	No Emission Cost Case	11.68	60.6%
Texas	NG Plant	High Emission Cost Case	7.52	46.0%
Texas	NG Plant	High Capital Cost Case	3.36	17.6%
		State-Plant Mean Price	7.95	
		State-Plant Mean Freq		44.2%
Washington	Coal Plant	Base Case	12.37	44.2%
Washington	Coal Plant	No Emission Cost Case	17.93	58.5%
Washington	Coal Plant	High Emission Cost Case	9.82	37.0%
Washington	Coal Plant	High Capital Cost Case	3.77	12.2%
		State-Plant Mean Price	10.97	
		State-Plant Mean Freq		38.0%
Washington	NG Plant	Base Case	15.77	68.4%
Washington	NG Plant	No Emission Cost Case	19.00	75.0%
Washington	NG Plant	High Emission Cost Case	13.41	62.7%
Washington	NG Plant	High Capital Cost Case	7.11	30.1%
		State-Plant Mean Price	13.82	
		State-Plant Mean Freq		59.0%
Oregon	Coal Plant	Base Case	20.83	58.8%
Oregon	Coal Plant	No Emission Cost Case	28.16	71.9%
Oregon	Coal Plant	High Emission Cost Case	17.18	51.5%
Oregon	Coal Plant	High Capital Cost Case	7.92	21.4%
		State-Plant Mean Price	18.52	
		State-Plant Mean Freq		50.9%

Oregon	NG Plant	Base Case	22.28	77.5%
Oregon	NG Plant	No Emission Cost Case	25.43	81.8%
Oregon	NG Plant	High Emission Cost Case	19.78	73.5%
Oregon	NG Plant	High Capital Cost Case	11.62	40.8%
		State-Plant Mean Price	19.78	
		State-Plant Mean Freq		68.4%
Colorado	Coal Plant	Base Case	28.55	68.2%
Colorado	Coal Plant	No Emission Cost Case	37.14	79.6%
Colorado	Coal Plant	High Emission Cost Case	24.08	61.3%
Colorado	Coal Plant	High Capital Cost Case	12.40	29.4%
		State-Plant Mean Price	25.54	
		State-Plant Mean Freq		59.6%
Colorado	NG Plant	Base Case	27.76	82.8%
Colorado	NG Plant	No Emission Cost Case	30.86	85.9%
Colorado	NG Plant	High Emission Cost Case	25.18	79.7%
Colorado	NG Plant	High Capital Cost Case	15.78	48.6%
		State-Plant Mean Price	24.89	
		State-Plant Mean Freq		74.2%
Nevada	Coal Plant	Base Case	12.36	44.0%
Nevada	Coal Plant	No Emission Cost Case	17.47	57.1%
Nevada	Coal Plant	High Emission Cost Case	9.90	37.2%
Nevada	Coal Plant	High Capital Cost Case	3.79	12.3%
		State-Plant Mean Price	10.88	
		State-Plant Mean Freq		37.6%
Nevada	NG Plant	Base Case	14.56	65.4%
Nevada	NG Plant	No Emission Cost Case	17.25	71.4%
Nevada	NG Plant	High Emission Cost Case	12.52	60.2%
Nevada	NG Plant	High Capital Cost Case	6.42	27.7%
		State-Plant Mean Price	12.69	
		State-Plant Mean Freq		56.2%
New Mexico	Coal Plant	Base Case	14.97	49.4%
New Mexico	Coal Plant	No Emission Cost Case	21.09	63.3%
New Mexico	Coal Plant	High Emission Cost Case	12.07	42.1%
New Mexico	Coal Plant	High Capital Cost Case	4.95	15.1%
		State-Plant Mean Price	13.27	
		State-Plant Mean Freq		42.4%

New Mexico	NG Plant	Base Case	16.66	69.3%
New Mexico	NG Plant	No Emission Cost Case	19.44	74.7%
New Mexico	NG Plant	High Emission Cost Case	14.50	64.4%
New Mexico	NG Plant	High Capital Cost Case	7.75	31.5%
		State-Plant Mean Price	14.59	
		State-Plant Mean Freq		60.0%
Georgia	Coal Plant	Base Case	18.77	55.8%
Georgia	Coal Plant	No Emission Cost Case	25.70	69.2%
Georgia	Coal Plant	High Emission Cost Case	15.37	48.5%
Georgia	Coal Plant	High Capital Cost Case	6.83	19.2%
		State-Plant Mean Price	16.67	
		State-Plant Mean Freq		48.2%
Georgia	NG Plant	Base Case	21.55	77.0%
Georgia	NG Plant	No Emission Cost Case	24.94	81.8%
Georgia	NG Plant	High Emission Cost Case	18.91	72.5%
Georgia	NG Plant	High Capital Cost Case	11.03	39.8%
		State-Plant Mean Price	19.11	
		State-Plant Mean Freq		67.8%
Virginia	Coal Plant	Base Case	11.85	43.1%
Virginia	Coal Plant	No Emission Cost Case	17.19	57.2%
Virginia	Coal Plant	High Emission Cost Case	9.40	36.0%
Virginia	Coal Plant	High Capital Cost Case	3.55	11.7%
		State-Plant Mean Price	10.50	
		State-Plant Mean Freq		37.0%
Virginia	NG Plant	Base Case	14.03	64.4%
Virginia	NG Plant	No Emission Cost Case	16.72	70.7%
Virginia	NG Plant	High Emission Cost Case	11.99	59.0%
Virginia	NG Plant	High Capital Cost Case	6.08	26.8%
		State-Plant Mean Price	12.20	
		State-Plant Mean Freq		55.2%
Pennsylvania	Coal Plant	Base Case	20.11	57.7%
Pennsylvania	Coal Plant	No Emission Cost Case	27.06	70.4%
Pennsylvania	Coal Plant	High Emission Cost Case	16.59	50.5%
Pennsylvania	Coal Plant	High Capital Cost Case	7.55	20.7%
		State-Plant Mean Price	17.83	
		State-Plant Mean Freq		49.8%

Pennsylvania	NG Plant	Base Case	22.76	78.4%
Pennsylvania	NG Plant	No Emission Cost Case	26.16	82.9%
Pennsylvania	NG Plant	High Emission Cost Case	20.09	74.2%
Pennsylvania	NG Plant	High Capital Cost Case	11.92	41.7%
		State-Plant Mean Price	20.24	
		State-Plant Mean Freq		69.3%

8) Tables and Figures

Figure 1: Average State/Plant Type CEO Premiums over all Scenarios (μ)

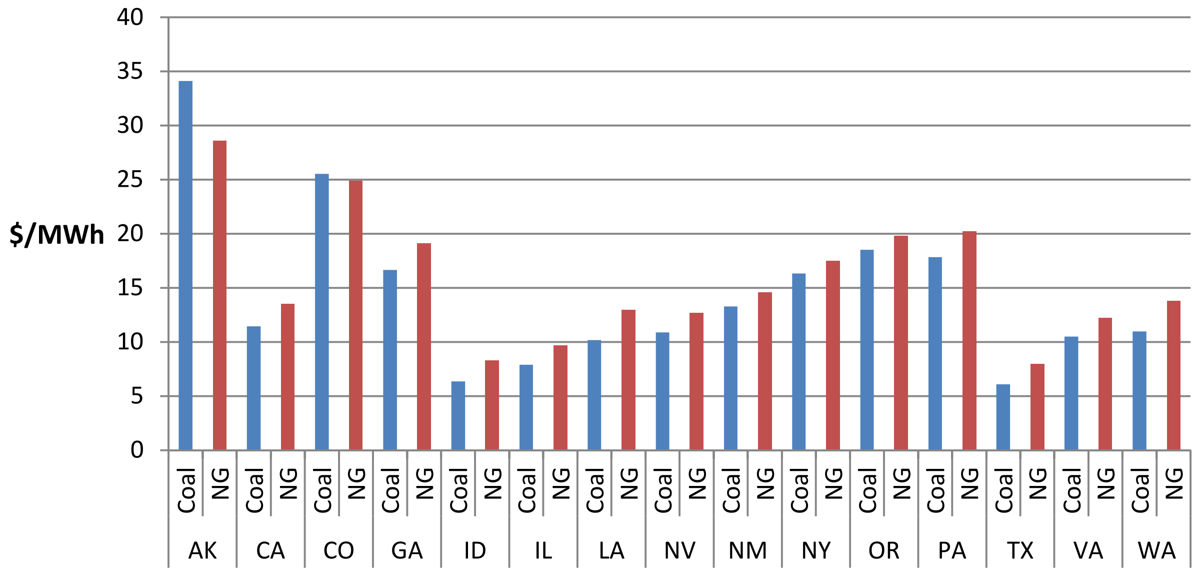


Figure 2: Average State/Plant Type Exercise Frequencies over all Scenarios

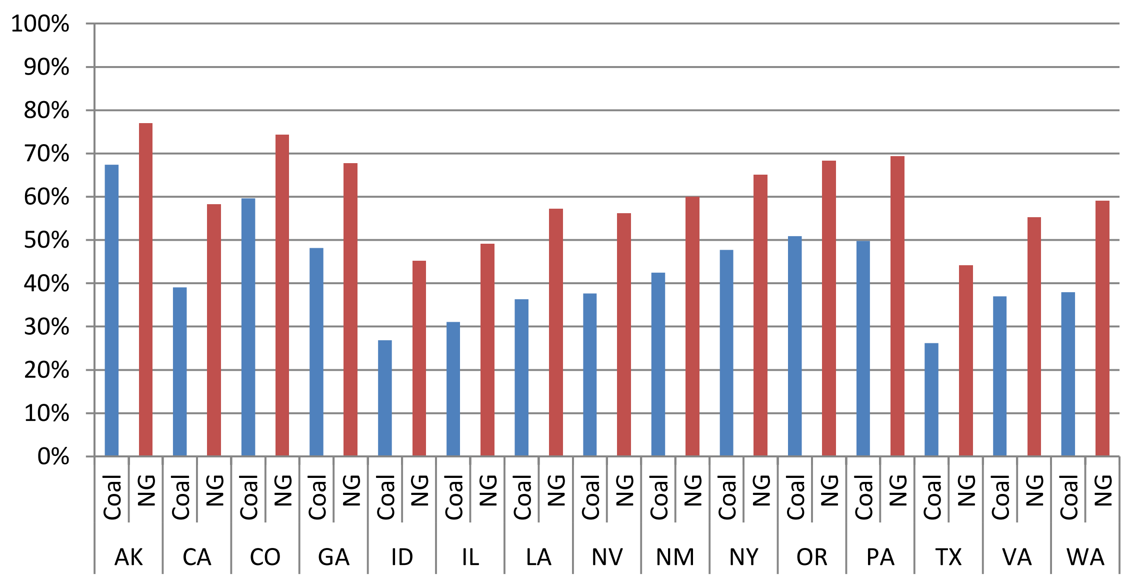


Figure 3: Standard Deviations of CEO Premiums by State/Plant Type (σ)

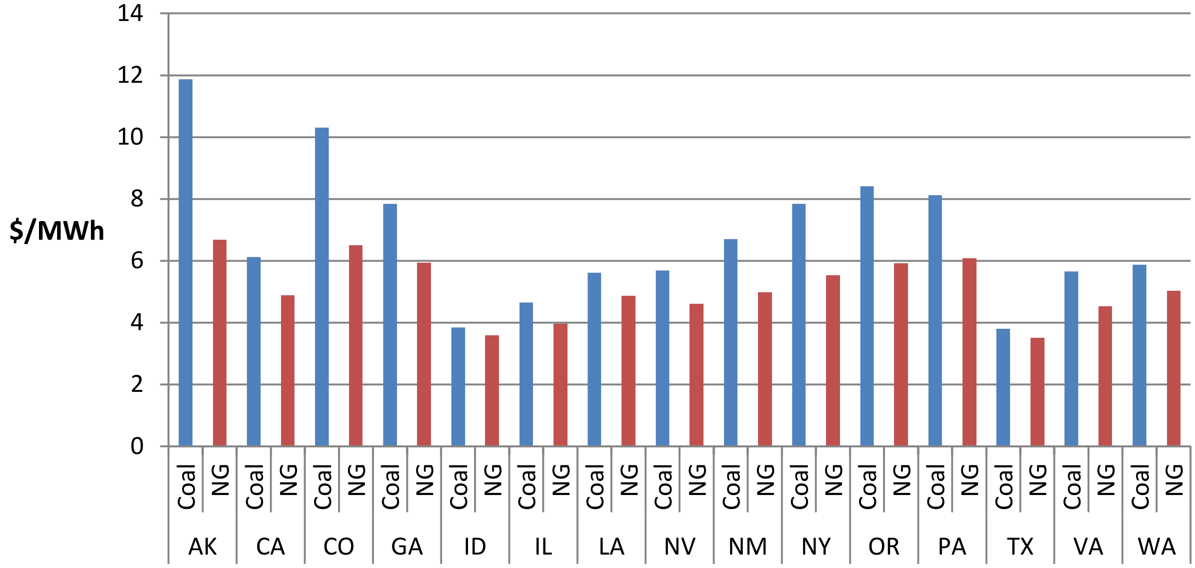


Figure 4: Coefficient of Variation of CEO Premiums by State/Plant Type (σ/μ)

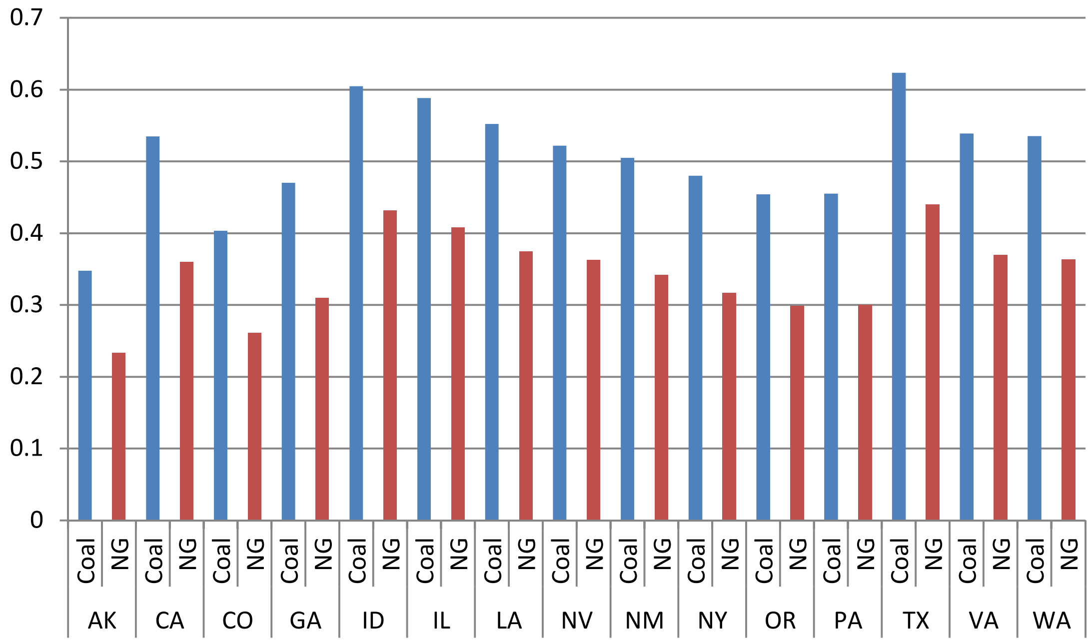
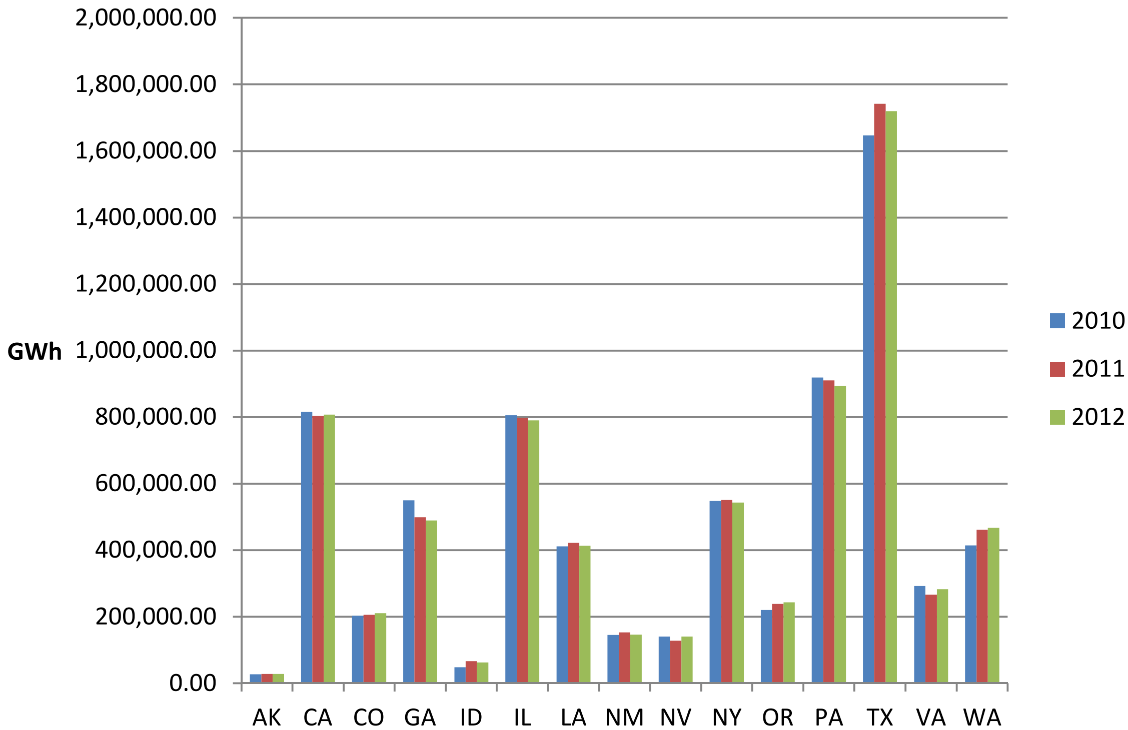


Figure 5: Recent Energy Generation in Select States [6]



[6] Graph produced using data obtained from U.S. Energy Information Administration. November 12, 2013.

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