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Geometric Brownian Motion Modeling of the Houston-Galveston Nitrous Oxide Cap and Trade Market

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Geometric Brownian Motion Modeling of the Houston-Galveston Nitrous Oxide Cap and Trade Market

by

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Dedication

For Kimberly and Lily. I couldn’t have come this far without your dedication and encouragement.

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Geometric Brownian Motion Modeling of the Houston-Galveston Nitrous Oxide Cap and Trade Market

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Texas' Mass Emission Cap and Trade program is a mandatory Nitrous Oxide (NOx) abatement program for medium and large stationary sources located in the Houston-Galveston ozone non-attainment area. Effected companies are required to upgrade equipment to meet the current best achievable NOx control technology (BACT) standards or to purchase emission credits in sufficient quantity to cover the difference in emissions between existing equipment and equipment meeting the BACT standard. With over 260 participating companies, the market for emission credits is ever changing, making it difficult to evaluate whether the lowest cost decision is to upgrade equipment or to purchase NOx emission credits. Because equipment upgrades are capital investments, a well informed, rational decision can have a significant impact on the corporate balance sheet. The objective of this research is to aid the decision maker by predicting credit prices based on a Geometric Brownian Motion model based on historical NOx emission credit transactions. The predicted credit price is useful in evaluating the likelihood of the equipment upgrade option being a favorable or unfavorable decision. For the examined cases, modeled results indicate that equipment upgrade is the more cost effective option.

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Section 1: Cap and Trade Primer

Emissions cap and trade programs became items of household discussion in 2006 during climate change debates on the domestic and world environmental stage and with the release of Al Gore's *An Inconvenient Truth*[1]. Today, business entities that have not been historical proponents of increased environmental regulation are participating in discussions on the creation of a cap and trade system for currently unregulated carbon emissions[2] (CO_2). Industry's largest industrial sources, and therefore biggest polluters, are participating because changing regulation and environmental practices can have a significant impact on corporate balance sheets[3]. In order to hedge the financial risk associated with regulatory uncertainty, these large industrial firms aim to focus the debate, provide technical assistance to regulators, and understand the nature of the new rules before they are written into law.

The concern about air emissions stems from federal National Ambient Air Quality Standards (NAAQS) which were instituted as part of the Clean Air Act of 1971 to protect public health. Several air pollutants which the NAAQS protect against are responsible for respiratory distress, asthma, and associated maladies. The primary pollutants (also known as *criteria pollutants*) regulated include carbon monoxide: an asphyxiant, lead, nitrogen oxides (NOx): an ozone precursor, particulate matter and ozone, respiratory irritants, and sulfur dioxide (SO_2): an contributor to acid rain. National standards for these criteria pollutants are set at levels which are protective of public health. If the standards are met, there should be no risk of respiratory illnesses in normal, healthy populations. In certain parts of the country with large industrial bases or in metropolitan areas with significant levels of commuter traffic, the NAAQS standards are not being met. Specialized measures above and beyond general control and emission standards published in the Clean Air Act are required in order to return these areas of non-attainment into attainment of the standard. Nitrogen oxide, the criteria pollutant of interest to this research, is not by itself a health concern, but it contributes to ground level ozone formation which irritates both oral and lung tissues. While ozone high in the atmosphere is necessary and beneficial for shielding the earth from harmful solar radiation, at low levels where it cannot easily disperse, ozone creates smog which reduces visibility and creates health problems.

The theory behind cap and trade systems is as follows: meteorological and climatological models establish a baseline amount of pollutant than can be emitted into the atmosphere without adverse effects, such as reduced visibility and health problems. By capping the emissions of this "problem" pollutant to no more than what the model indicates as the baseline, air quality should, at a minimum, become no worse than it currently is. No new emissions (above the modeled cap) of the pollutant in question are permitted, and pollutant "allowances" are given to operations currently emitting this pollutant. Before the allowances are set, however, 5-10% of the modeled pollutant amount is subtracted from the modeled total and set aside as an "environmental contribution" to create a buffer zone between actual emissions and the modeled threshold. This reduces the total allowance "cap" to 90-95% of what the airshed is believed to accommodate. Amongst the participating sites, pollution allocations are divided up based on several factors that may include historical emissions, level of activity, or efficiency levels and allocated to those participating sites.

Companies receiving allowances are then allowed flexibility in their operations as long as they follow the broad stipulations of the program and possess enough allowances to offset operating emissions during that year. As there is now a set number of allowances, facilities may choose to upgrade equipment to newer, more efficient models or undergo process changes that emit less of the controlled pollutant. These alterations create un-needed allowances that may be sold to other companies who choose to not meet emission standards. Cap and trade program authors assume that industrial and economic growth in the area will increase the demand for production capacity, and therefore increase the demand for emission credits. This natural growth, along with growth from new companies that move into the regulated area and need allowances, creates a market in which the pollutant "credits" increase in value. Installation of more efficient equipment becomes an economic incentive rather than buying increasingly expensive pollution credits each year.

While cap and trade programs are demonstrated to be environmentally effective[4], the amount of environmental impact per financial impact is still being debated. Because of the increasing political interest in cap and trade programs, congressional hearings are being conducted to discuss the feasibility of such a program[5] for greenhouse gasses.

Any additional regulation will have an impact on corporate capital and operational costs as more methods and procedures are changed to comply with the additional rules. Current congressional interest is in the quantification of those financial impacts on energy markets by implementing cap and trade programs. In September of 2006, Senators Bingaman, Landrieu, Murkowski, Specter, Salazar, and Lugar requested analysis of a national cap and trade program to regulate greenhouse gasses[6]. As a result of the carbon trading proposal, natural gas prices, an effected commodity because of its use in electric power generation, are estimated to increase 6% to 11% in the next 10 to 20 years because the price of purchased allowances will be passed on to the consumer in fuel costs[7].

To maintain industry equity, only facilities above a certain size or emitting more than the program threshold are targeted for participation in emission cap and trade programs. Smaller companies are exempted because their administrative and market costs outweigh any benefit of the program.

Two scenarios are generally accepted as the primary financial drivers of cap and trade regulation: favorable allocation of tradable allowances from early participation in the program[8] and brokerage of tradable allowances after the program is established[9]. Regardless of the approach, industry is cooperating to try and capitalize on the financial potentials of this emerging market.

Section 2: Texas' Nitrogen Oxide (NOx) Cap and Trade Program

Texas' flagship cap and trade program (several smaller programs also exist in Texas), named the Mass Emission Cap and Trade Program (MECT), was established in 1993 to limit nitrogen oxides (listed generically as NOx, includes NO and NO_2) emissions in the Houston-Galveston (HGA) area. Baseline emissions were calculated based on historical data and the allowances generated from this baseline data were distributed to industrial sources in 2002. In order to encourage equipment upgrades and stimulate market demand for tradable allowances, initial allocations of 231,000 tons were stepped down 35% in 2004, 60% in 2005, 70% in 2006, and 75% in 2007, leaving a permanent 48,000 ton allowance base in perpetuity from 2008 on[10].

Although Texas' NOx cap and trade program targets a specific set of industries, primarily petrochemical, due to geographic location, cap and trade market theory is still applicable. The market operates in a manner that encourages upgrades of old, inefficient equipment and creates a means for companies to maintain operational flexibility while maintaining regulatory compliance.

Implementation of the Houston-Galveston MECT was a compromise solution. Initial estimates of NOx reductions that would attain the EPA's ambient ozone levels were set at 90%. Stakeholders and industry argued that a 90% reduction was too aggressive and counter-offered an 80% reduction level. The final solution was to reduce NOx emissions by 80% and institute a NOx cap and trade program to financially incentivize further reductions.

Savvy environmental staff realize that while it may be easier to look to the market to provide emission credits required for operation, it may not always be the most economically sound choice. There exists a tradeoff between installation of additional controls, which serve the dual purpose of bringing the unit closer to, or meeting, the required emission standards and possibly generating credits to sell and buying credits. Economic analysis of differing technologies is a high priority to both the regulatory agencies, as it determines what upgrades are reasonable, and to the regulated community, as they must determine what capital and operating outlays are acceptable to the bottom line.

While in reality, the decision about whether to upgrade inefficiently controlled equipment has just as much to do with environmental costs and benefits as it does with company management practices, public relations and the cost of capital, a method for evaluating this decision is not readily available to participants in the cap and trade program.

Section 3: Allowances and the Commodity Pricing Models

Emission credits fit the definition of a commodity: a "homogenous item which may be freely bought and sold"[11]. Specifically, companies are purchasing the right to emit a certain amount of NOx. Since emission credits are an intangible item, they don't suffer from many of the price influencing roadblocks that hard goods face. For example, transportation costs that would normally affect the spot market price of a bushel of corn cannot alter the value of an electronically-traded commodity. Additionally, emission credits are not subject to storage costs. Credits (unless expired) may sit in a brokerage account for an indefinite amount of time with no loss of value.

Without these impositions on cost, the emission credit market is more representative of the true cost of the commodity and not the commodity, logistics, and oversight costs of a tangible asset.

Many would argue that greenhouse gas credit markets are too volatile and defy conventional commodity pricing models. In most cases, this is true due to the fact that greenhouse gas policy is still a highly politicized issue and no substantial definition has been assigned to the market[12]. Carbon credits are indeed being traded, but without any federal or state programs (and associated guidelines) to define generation, supply, and regulation of the cap, the current carbon market is not representative of a true commodity at this time[13]. The problem here is that there is not one fixed commodity to be bought. Several types of carbon credits are available for purchase (Chicago Climate Exchange, Kyoto-compliant credits, etc.) and even more varied market analyses on futures values for these credits[14] exist. Not only do the different brands of credits introduce uncertainty into decision making, but the lack of a standardized market analysis makes price estimation difficult.

This volatility is not present when a specific set of definitions are placed on the scope, purpose and administration methodology of a greenhouse gas cap and trade program. When limited to regulation of one specific pollutant, in a specific region, with a dedicated plan for allocations, and a regulatory plan that drives demand, mass emissions cap and trade programs are very effective. The cap and trade pilot program in the US for sulfur dioxide emissions reduced SO_2 emissions in the industrial northeastern states by 60%[15], by allocating tradable allowances generated based on participating industrial sources' average heat input[16].

The HGA NO_x Mass Emission Cap and Trade (MECT) program operates in much the same way as the Northeast's SO_2 program. Initial allocation of allowances was based upon historical operating data and a standardized emission rate. Participating facilities then received an allocation proportional to their level of activity.

Section 4: Review of Similar Research

Even though emission cap and trade programs have been successfully implemented in markets around the world, debate still occurs about whether cap and trade is the most appropriate form of air pollution control. This debate has been ongoing since Coase first proposed a market based approach[17] to controlling societal ills like air pollution. Subsequent research by Weitzman[18], Lutter[19], and Murray, et. al. seeks to determine a happy medium between societal benefits, like reduced pollution levels, and program compliance costs[20].

Other areas of cap and trade research areas include econometric analyses done on financial impacts to industry and the community. Specific programs are evaluated for efficacy by comparing estimated program costs with actual costs. Programs which improve air quality and do so according to estimated cost are considered successful. Ellerman demonstrates the success of the Northeastern states' SO_2 cap and trade program in this manner, but finds that cap and trade program accounting practices are often inconsistent. Other research (Burtraw, et. al.) tracks emission credit prices over the life of the market and offers theories as to why prices may have fluctuated up or down[21]. Neither this *ex post facto* analysis nor the theoretical discussions about the most appropriate mechanism for minimizing cost burdens to achieve lower pollution levels address the use of credit price models to aid decision makers involved in cap and trade programs.

Introduction of legislation mandating and proposing carbon cap and trade both in Europe and the U.S. has generated new interest and therefore new research about emission credits. This research not only addresses the relative strengths and weaknesses of cap and trade as a pollution control mechanism, but also addresses emission credits as financial instruments, which can be hedged against price volatility[22].

Creation of the European Union's (EU) Emission Trading System (ETS) in 2005 provided a market in which CO_2 emission credits are traded. Although similar in concept to Texas' MECT program, the inclusion of 25 EU member states makes the ETS the largest emission trading market in the world. Benz and Trück employ stochastic GARCH and regime switching models in order to simulate CO_2 emission credit prices in ETS. Although the time from which data points were collected was short (~2 years), the high trading volume allows for good fitting of the GARCH model to the empirical data[23]. Benz and Trück were able to reliably estimate a mean value (and accompanying distribution of credit prices) for one day-ahead forecasts. Daskalakis et. al. employ seven different modeling techniques, including Geometric Brownian Motion (with and without jumps), Constant Elasticity of Variance, and Mean Reversion Processes (with and without jumps). Of these seven models, the Geometric Brownian Motion process augmented by jumps was found to be the best fit for both historical allowance prices and for overall market volatility[24].

This research intends to create a Geometric Brownian Motion mechanism by which to evaluate the decision to continue operating old equipment through the purchase of annual emission credits to offset high emission levels, or to upgrade to new equipment to avoid purchasing annual credits. Two sample cases are established to provide a framework for evaluating modeled results.

Section 5: Case 1: Upgrade of a Steam Boiler with Catalytic Control

One of the most common types of industrial equipment is the steam boiler. These boilers burn natural gas (or similar fuel) to produce electricity, generate steam, provide useful heat or energy for industrial, commercial, or institutional use[25]. Since this is a simple combustion process, normal combustion products, of which NOx is a component, are emitted into the atmosphere.

For the purposes of this evaluation, a medium sized steam boiler that would have been considered *state of the art* in 1999 is considered. This boiler is of medium size, 100 million British thermal units (MMBTU) and meets Texas Commission on Environmental Quality (TCEQ) emission standards from 1999 via engineering design instead of add-on controls.

To establish a NOx emission baseline for a hypothetical "old" steam boiler, the TCEQ's default NOx emission factor considered Best Available Control Technology (BACT) from 1999 will be used. In many cases, this estimate may be conservative as steam boilers can often have an effective lifespan of 20 to 30 years when well maintained. Old boilers may, in fact, emit more emissions than would have been expected for a boiler with 10-year old technology. As a counterpoint, a hypothetical "new" steam boiler will use the current NOx emission factor for BACT. This is considered the standard to which all newly constructed boilers are held.

In order to stay in compliance with current environmental regulations in the Houston/Galveston area, the operator is required to "retire", i.e. turn into the TCEQ, NOx credits in an amount equal to the amount emitted by the facility during the preceding calendar year. Due to program design, operators may be allocated a portion of their total credit burden, according to equipment type and size. If the amount of NOx emitted is greater than the number of credits held by the equipment operator, credits must then be purchased to cover the deficit. If the amount of NOx emitted is less than the number of credits held, the extra credits may be sold or traded as needed.

For this 100 MMBTU boiler, emissions that would be expected from the 1999 technology are calculated and compared to emissions that would be expected from current technology.

Table 1: Steam Boiler Emission Comparison – No Control

Boiler Specifications	Emission Factor (lb NOx/MMBTU)	NOx Emissions (tons per year)	Credits Needed (tons)
100 MMBTU/hr	0.06 (10-year BACT)	26.28	21.90
100 MMBTU/hr	0.01 (Current BACT)	4.38	--

Note: Emissions Calculation Basis (Firing Rate (MMBTU/hr) x Emission Factor (lb/MMBTU) x 8,760 hours of annual operation / 2000 lbs per ton)

As an alternative to operating the old boiler and purchasing 21.90 credits, the operator could instead purchase add-on controls to reduce some of the compliance burden. According to the U.S. Environmental Protection Agency's Cost Control Manual, the cost of installing a Non-selective Catalytic Reduction (SNCR) unit, which would reduce emitted NOx by 50% (by injecting ammonia into the exhaust stream to promote conversion of NOx to elemental nitrogen), to a boiler is $950 per MMBTU[26]. For this 100MMBTU boiler, typical SNCR capital costs (not including ancillary installation costs) are $95,000. This cost, however, only controls half of the NOx being emitted from the boiler, reducing the emissions from 26.28 tons per year to 13.14 tons per year.

Operating and maintenance costs are estimated to be $10,000 per year for maintenance and ammonia costs. In addition to the capital and operating costs, the operator of this boiler would also have to purchase NOx credits to cover the additional balance in excess of 4.38 tons per year, the amount allocated to the operator by the TCEQ.

Table 2: Steam Boiler Emission Comparison – SNCR Control

Boiler Specifications	Emission Factor (lb NOx/MMBTU)	NOx Emissions (tons per year)	Credits Needed (tons)
100 MMBTU/hr	0.03 (10-year BACT)	13.14	8.76
100 MMBTU/hr	0.01 (Current BACT)	4.38	--

Note: Emissions Calculation Basis (Firing Rate (MMBTU/hr) x Emission Factor (lb/MMBTU) x 8,760 hours of annual operation / 2000 lbs per ton)

How does a decision maker evaluate the cost of purchasing 8.76 tons of annual credits with varying annual cost and a fixed $95,000 for capital improvements versus the variable annual cost of purchasing the full 21.9 tons required for compliance and $10,000 annually for maintenance? Results generated by the NOx credit price model will aid in evaluating this decision.

Section 6: Case 2: Replacement of a Reciprocating Compressor Engine

Equally common in the Houston Galveston area is the reciprocating internal combustion engine (ICE). These units function as emergency backup generators, fire water pumps, and compressors. Reciprocating engines can be fired with many fuels, including diesel, gasoline, and natural gas. Due to the availability and ease of distribution at industrial sites, natural gas is often preferred over diesel. Combustion of natural gas by a reciprocating engine is a well understood process and NOx emissions from these units have been thoroughly quantified and documented.

As in the steam boiler example, a reciprocating engine consistent with 10-year old technology and engineering practices is compared to a *state of the art* engine of the same make, model and size. While engines manufactured by White and Waukesha are common in these applications, the Caterpillar Model 3516 is preferred for comparison due to the availability of detailed emission data on the Caterpillar website[27] and other sources.

Table 3: Reciprocating Engine Emission Comparison

Engine Specifications	Emission Factor (g/hp-hr)	NOx Emissions (tons/year)	Credits Needed (tons)
16 cylinder; 1300 hp; 8,760 hours per year	3 (10-year old emission factor)	37.66	31.38
16 cylinder; 1300 hp; 8,760 hours per year	0.5 (current standard emission factor)	6.28	--
16 cylinder; 1300 hp; 8,760 hours per year	0.25 (lowest achievable emission factor)	3.14	-3.14

Note: Emission Calculation Basis (Emission Factor (g/hp-hr) x horsepower x 8,760 hours of operation ÷ 453.6 grams per pound ÷ 2,000 pounds per ton)

The 90%+ reduction in emissions appears drastic because it is. The current BACT emission factor of 0.25 g NOx per horsepower hour factor represents the minimum currently achievable engineering design emission rate for an engine of this size equipped with catalytic reduction of NOx in the exhaust gas stack. This great reduction in NOx emissions over a relatively short time period is due to both improvements in technology as well as the regulation of NOx as a criteria pollutant[28].

Due to the premium placed on NOx reductions in the Houston/Galveston area, the maximum acceptable emission rate for this type of engine is 0.5 g NOx/hp-hr. Operating the old engine will require the purchase of 31.38 NOx credits just to stay in compliance with current regulations. If the company were to replace the engine, the new engine would not only meet all of the required emission standards and eliminates the need to purchase credits to offset the balance, but the over-control (above and beyond 0.5 g NOx/hp-hr) of the engine's emissions frees up a portion of the TCEQ allocated credits for sale on the credit market. Were the engine to operate at the lowest achievable 0.25 g NOx/hp-hr, annual emissions would total 3.14 tons, leaving 3.14 credits for sale.

Replacement costs for an engine of this size are significant, approximately $450,000[29]. Annual fuel costs are estimated to be around $250,000. The cost of compliance, even at a nominal credit price of $2000/ton, is also significant on an annual basis. With variable credit prices, how can an environmental manager convince the capital improvements department that replacing an old engine is a fiscally sound decision? As in the boiler replacement case, the results of the credit price model can aid in making this decision.

Section 7: Preparation of Data

Records of credit transactions from 2002 to 2009 are maintained on the TCEQ Emission Banking and Trading website. Since it is normal for several transactions to be received by the TCEQ on the same day, transactions are identified by a unique project number instead of a date. Each project number maintains a record of the number of credits traded, date traded, and the price per credit.

Since the project number is not relevant to the credit price model, data was entered into an Excel spreadsheet using the transaction date as a unique identifier. In the event that more than one transaction occurred on the same day, the duplicate transaction date was shifted either one day earlier or one day later depending on whether there was already a transaction immediately before or after the date in question. Were the model constructed to predict credit prices at discrete times in the future, this would not be an appropriate way to organize the data, but since the model is only concerned with a credit price forecast *a* certain number of transactions forward of the current point in time and not a price forecast on a specific date in the future, transaction order is more important than transaction date. Additionally, since transaction data may take up to a week to be entered into the TCEQ database, there is not a real time market price indicator in the NOx credit market, and therefore no spot price for these credits. Because current information for participating companies executing a transaction could be lagging by up to a week, this adjustment to the transaction date for modeling purposes introduces less variability in the data than already exists due to the TCEQ recordkeeping.

Data was grouped according to the year of the transaction. Since the model aims to simulate credit price according to future periods instead of discrete dates, it is appropriate to calculate metrics (growth rate, volatility) as aggregates instead of by individual credit year.

Section 8: Geometric Brownian Motion (GBM) in the HGA NOx Market

The first task in building a GBM model is to define the goals and parameters. Modeling of the individual year credit prices is based on the equation for Arithmetic Brownian Motion:

$$dV = \alpha\ Vo\ dt + \sigma\ Vo\ dWt \qquad \text{Equation 1}$$

Where

- dV is the expected value of the credit,
- α is the growth rate of the credits in a particular year,
- *Vo* is the initial credit price
- σ is the volatility of the credit stream in a particular year,
- *Wt* is Wiener Process (normal distribution with mean 0 and standard dev. 1).

For ease of calculation, a slightly different, normally distributed version of the Arithmetic Brownian Motion equation[30] based on the logarithmic transformation of dV is used:

$$\ln(V) = \ln(Vo) + (\alpha - \frac{1}{2}\sigma^2)t + \sigma\ \sqrt{t}\ (Wt) \qquad \text{Equation 2}$$

Since the logarithmic form is not intuitive for comparison of modeled results, both sides of the equation are raised to the exponent *e*:

$$V = Vo\ e^{([\alpha - \frac{1}{2}\sigma^2]t + \sigma\sqrt{t}(Wt))}$$

Equation 3

This form of the Geometric Brownian Motion equation makes it possible to calculate predicted values for V based on input growth rates (α), credit volatility (σ), and lognormally distributed random numbers (*Wt*). The use of spreadsheet software such as Excel simplifies the modeling process due to the built in statistical analysis tools and automated formula calculations. The model inputs calculated from historical data are summarized in Table 4.

Table 4: Model Input Variables

Drift Rate (α)	Volatility (σ)	No. of Transactions
2.69%	0.13	78

Beginning in 2004, the model sharply increases over the historical prices due to a high level of price volatility that year. Not surprisingly, 2004 was the first year that the NOx Cap and Trade market experienced a reduction in the allowance cap, which prompted some companies to look for credits on the open market. The observed shift in demand for credits did not uniformly increase credit prices, but may have contributed to some of the high priced credit transactions during this time period.

Due to the allowance stepdowns discussed in Section 2, the market experienced more credit price volatility because the variable size of the credit pool added uncertainty about the market's future. It is likely that credit prices were artificially inflated during 2002-2006 because participating companies may have been willing to pay increased prices as a hedge against possibly unavailable credits in the following years.

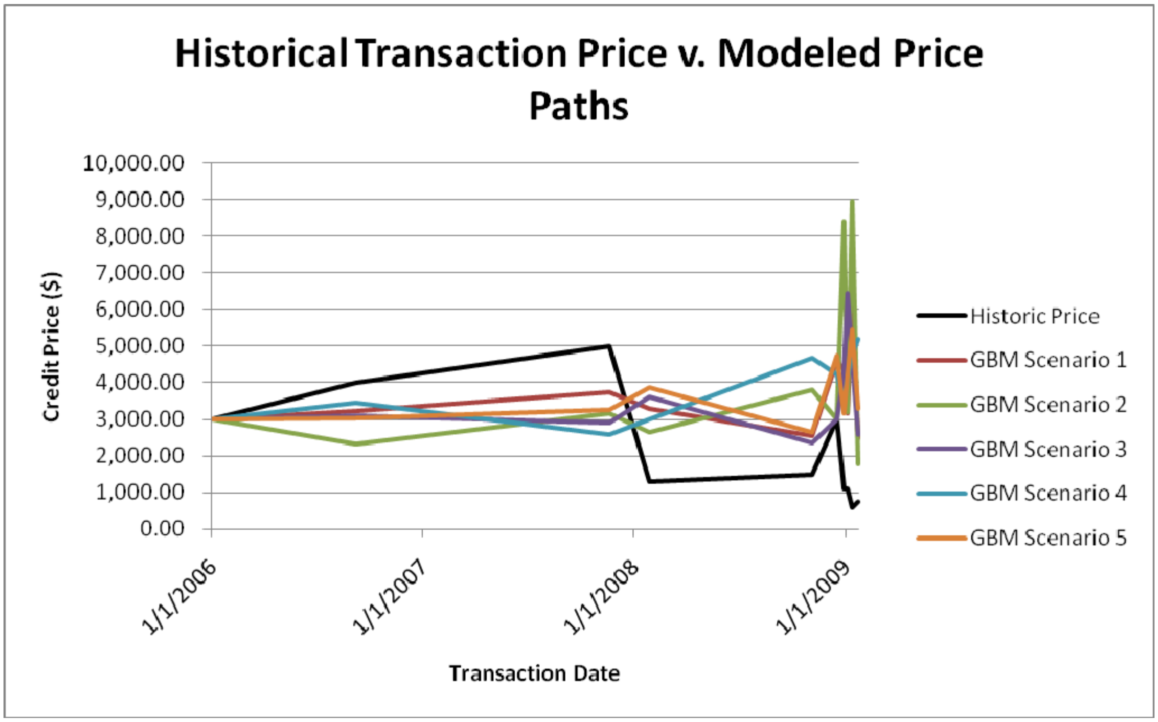
Historical transaction data acquired from the TCEQ database is available from 2002 to January 2009. The drift rate was calculated to be the mean of the percent changes in the natural log of price from transaction to transaction for the entire data set, 2002-2009.

Volatility was calculated by calculating the standard deviation of the percent change in the natural log of price from transaction to transaction for 2007 to 2009 data. Using the calculated growth, volatility inputs and normally distributed random numbers, calculated credit prices were determined using the lognormal adjusted GBM equation (Equation 3). The equation uses the first historical transaction price, \$3000 per ton of NOx (first transaction price in 2007), as a starting point for the model.

In order to satisfy the “random walk” component of the GBM formula, a random normal distribution with a mean of 0 and standard deviation of 1 was created for each period simulation using @Risk’s *RiskNormal* function.

To graphically demonstrate the concept of Monte Carlo simulation, multiple instances of this modeled price path can be set up in Excel (Figure 1). As seen in the figure, the GBM paths approximate the historical trade data with some significance. One path appears to grossly overestimate predicted credit prices, but most paths generally follow (perhaps slightly underestimating) the actual price data. Figure 1 represents only five (Paths A-E) GBM paths, each of which is simulated according to Equation 3. Increasing the number of these modeled runs from 5 to 100 or even 1000 (and using dedicated simulation software like @Risk) can reduce the relative impact of outliers and estimate a more “general” average future price.

Figure 1: Historical Trade Data v. Modeled Price Paths



Section 9: Analysis of Modeled Data

In order to use calculated drift rate and volatility values based on historical prices, Palisade's @Risk add-in for Excel was used. In order to iteratively simulate the GBM process, a simulation scenario was created in which GBM values at evenly spaced intervals were simulated by @Risk. During the simulation, @Risk uses the calculated drift rate and volatility and generates random numbers (normally distributed random walk) to simulate a credit price according to the GBM equation (Equation 3).

For this analysis, the simulation was set up to iterate 1,000 times and generate expected value output. At the conclusion of the simulation, the results were graphically represented by a histogram.

The expected value histograms show a somewhat lognormal distribution in the early periods which widens due to compounded price volatility in the later periods. Were a larger historical trade record available, some of the variability seen in from the full data set would be averaged out in the distribution of the expected values.

While the number of data points used in the model is not large, their normal level of market volatility stabilizes the behavior of the model and maintains the credit price[31]. Each sample distribution shows reasonably good lognormal distribution (Appendix B), a feature that was missing in the early year samples in the 2002-2009 data set.

For the model to be valid, no administrative changes to the MECT program can occur. If the program is changed, the model will have to be re-simulated once enough transaction data is available to calculate model inputs.

Section 10: Refinements to the GBM Model

Several model refinements were considered to possibly eliminate errors inherent to the simulation. A sensitivity analysis, for example, could identify which input variables the GBM model is most sensitive to. Once the most critical variables are identified, an effort can be made to eliminate assumptions, sampling error, etc. in those variables and therefore the compounding of that volatility in the modeled calculations. In order to perform a sensitivity analysis, a distribution of values with means calculated based on historical data and a single standard deviation for both drift rate and volatility would need to be created and plugged into the simulation in place of the calculated values.

Consideration was also given to a careful review of the source data. Occasionally, trades will occur between two companies that are considered mutually beneficial. For example, trades can occur between sister companies or firms with shared property and/or equipment. In these situations, it can be advantageous for both companies to pay a price for credits that is under market value. If this data were easily identified, eliminating this data point would benefit both the results and the intent of the model to provide an accurate, unbiased estimate of future credit prices. Without speaking to each company that submitted a credit transaction, however, it is impossible to identify from the TCEQ data which transactions may have occurred at discount prices.

Both the sensitivity analysis and the elimination of discounted trades play a minor role in credit price modeling and further work trying to eliminate these errors would be outside the scope of this analysis. Several larger variables that could be refined to improve the model are addressed in the *Limitations of the Model* section.

Section 11: Modeled Results Summary

While a single predicted mean credit price has some value in evaluating the decisions posed in Case 1 and Case 2, the distribution of all 1,000 modeled values provides a broader and more realistic basis for evaluating those decisions. Instead of a single calculation to determine the costs of one option over another, a probabilistically distributed series of values used as an input (Appendix B) can generate a probabilistically distributed set of results. This approach does not improve the accuracy of a decision, but rather gives a wide angle view of the most and least probable decision scenarios. Instead of basing the decision on a single data point, many data points, both probable and improbable, are available to the decision maker.

The simulated results for the immediate future NOx credit transaction are consistent with a moderate growth rate. The distribution of modeled results indicates a strong bias towards more widely variable credit prices (Table 5). These results do not reflect the downturn in credit prices in late 2008 and early 2009 which may indicate this downturn was due to broader economic circumstances. A nation-wide recession reduces the demand for credits to supply new construction projects and expansion of existing facilities.

Table 5: Modeled Final Credit Prices

Credit Price ($)	*P1*	*P2*	*P3*	*P4*	*P5*	*P6*	*P7*	*P8*	*P9*	*P10*
0.00	0	0	0	0	0	0	0	0	0	0
500.00	0	0	0	0	0	0	0	0	0	0
1000.00	0	0	0	0	0	0	0	0	0	1
1500.00	0	0	0	1	3	6	9	11	13	15
2000.00	0	8	21	32	40	47	51	55	58	59
2500.00	61	109	124	129	129	126	122	118	114	111
3000.00	382	303	258	227	203	185	172	160	150	140
3500.00	409	318	266	232	209	190	174	163	153	145
4000.00	128	176	179	173	165	157	149	141	135	127
4500.00	19	64	92	104	110	112	112	110	107	107
5000.00	1	17	39	56	66	72	77	80	81	81
5500.00	0	4	14	26	36	45	52	55	59	61
6000.00	0	1	5	11	20	26	31	38	41	45
6500.00	0	0	1	5	9	15	21	24	29	32
7000.00	0	0	0	2	6	9	12	17	20	22
7500.00	0	0	1	1	2	5	7	9	13	16
8000.00	0	0	0	1	1	2	4	7	9	12
8500.00	0	0	0	0	0	1	3	5	5	8
9000.00	0	0	0	0	1	2	2	2	4	5
9500.00	0	0	0	0	0	0	0	2	4	4
10000.00	0	0	0	0	0	0	1	0	1	2
More	0	0	0	0	0	0	1	3	4	7

Section 12: Evaluation of Emission Credits as Financial Options

Having simulated emission credit prices for ten future transaction periods, a method for using credits to improve estimated project value must be established. Ownership of a set of allowances allows a company to “retire” those credits and operate older, less efficiently controlled equipment than would normally be required. In order to meet regulatory limits, operators could either purchase the new equipment or continue to use existing equipment and supplement that operation with emission credits (30 Texas Administrative Code 101.376). Both scenarios satisfy the regulatory requirements, but in many cases, existing equipment has plenty of useable life left, and the capital costs associated with upgrading existing equipment can be steep. This is no financial miracle, however, as the credits that allow this type of activity must be purchased annually and expressly for that purpose. The advantage of this option is that it allows a company flexibility to operate how they see fit.

Examine the case of a company that operates an inefficient compressor engine. Each year, the company has the option to purchase a new, more efficient engine (at a particular cost) that emits less NOx and requires fewer allowances or continue to operate the existing, inefficient engine and purchase more NOx allowances. In other words, Company X always has the choice to make a capital intensive outlay to reduce annual operating costs or maintain higher annual operating costs and not have to invest in new equipment.

In order to evaluate a capital decision that will last for many years, some assumptions have to be made. For example, the best way to decide whether to upgrade or to purchase credits would be to build a credit price estimation model whose estimates remain valid over the life of the capital equipment. Since it is not uncommon for compressor engines and boilers to last over twenty years, this is a difficult if not impossible task. In many cases, operations and maintenance (O&M) costs will increase as the equipment ages. In the two sample cases, unpredictable maintenance costs are ignored.

In order to use the model to assist with decision making, it is assumed that capital investments have a lifespan of 10 years and that the investment is financed such that the capital cost is paid in the first year and recurring operating costs are paid annually. In real life, of course, the capital cost will either be paid all at once, or over time including loan servicing payments each year until paid in full.

Examination of the data table (Table 5) and histogram of all 1,000 modeled credit prices for each period (Appendix B) indicates that the model-produced results lie on a lognormal distribution curve. Use of only the mean credit price for the decision analysis would ignore the other 999 modeled credit prices and not give an accurate representation of the modeled market behavior. It is preferred, therefore, to set up a second simulation and use the modeled credit price distribution as the credit price variable.

Both hypothetical cases as outlined in Sections 5 and 6 (Case 1 and Case 2) are set up to evaluate the costs associated with installing a capital improvement that will reduce the annual credit purchase burden and the cost associated with purchasing credits in order to comply with the requirements of the MECT program.

Both cases compare the sum of the total project NPV and the predicted price for the number of credits required in that scenario for both the upgrade and the credit purchase option.

Table 6: Case 1 (SNCR Upgrade) Cost Evaluation

No. of Credits Needed	8.76			**Capital investment**	95000
Discount rate	5.00%			**O&M Costs**	10000
Period	0	1	2	3	4
Credit Price	3,000.00	3,055.99	3,113.02	3,171.11	3,230.29
Net Cost	131,280.00	36,770.44	37,270.03	37,778.94	38,297.35
NPV	131,280.00	35,019.46	33,805.01	32,634.87	31,507.33
Total NPV	**431,799.69**				

Note: Actual Simulations are based on a 10-period time scale. The abbreviated 4-period model shown here is merely for illustration purposes.

Table 7: Case 1 (Credit Purchase) Cost Evaluation

No. of Credits Needed	21.90	**Capital investment**	0
Discount rate	5.00%	**O&M Costs**	0

Period	0	1	2	3	4
Credit Price	3,000.00	3,055.99	3,113.02	3,171.11	3,230.29
Net Cost	65,700.00	66,926.09	68,175.07	69,447.35	70,743.38
NPV	65,700.00	63,739.14	61,836.80	59,991.23	58,200.75
Total NPV	**623,955.84**				

Table 8: Case 2 (Engine Replacement) Cost Evaluation

No. of Credits Needed	-3.14	**Capital investment**	450000
Discount rate	5.00%	**O&M Costs**	250000

Period	0	1	2	3	4
Credit Price	3,000.00	3,055.99	3,113.02	3,171.11	3,230.29
Net Cost	690,580.00	240,404.20	240,225.13	240,042.71	239,856.89
NPV	690,580.00	228,956.38	217,891.27	207,357.92	197,330.85
Total NPV	**2,540,971.57**				

Table 9: Case 2 (Credit Purchase) Cost Evaluation

No. of Credits Needed	31.80			**Capital investment**	0
Discount rate	5.00%			**Variable cost per ton**	250000
Period	0	1	2	3	4
Credit Price	3,000.00	3,055.99	3,113.02	3,171.11	3,230.29
Net Cost	345,400.00	347,180.35	348,993.93	350,841.36	352,723.26
NPV	345,400.00	330,647.96	316,547.79	303,069.96	290,186.30
Total NPV	**3,086,451.80**				

In Case 1, the credit purchase option is never preferred. Even with a capital cost expenditure in the first year, the SNCR upgrade project NPV is significantly smaller than the NPV of the credit purchase option (Figure 2). The shape of the SNCR Upgrade NPV distribution is much more narrow than the distribution of the credit purchase option NPV which reflects the smaller impact of credit price volatility since less credits are required. The distribution of SNCR upgrade costs lies wholly to the left of the credit purchase distribution indicating that for every modeled credit price, the capital upgrade is the more cost effective option. Additionally, the distribution cumulative percentage curves (Figure 3) never overlap, confirming the distinct preference for the SNCR upgrade as the preferred option.

In Case 2, the model summary (Tables 8 and 9) indicates again that the credit purchase option is preferred. Because the operating costs are the same for both the existing and the new engine, the NPV comparison is reduced to capital costs versus credit purchase costs. Although a significant amount of credits are needed, the cost associated with purchasing those credits is still more costly than replacing an engine. While the credit purchase option distribution exhibits an expected lognormal shape, the simulated engine replacement distribution is extremely narrow (Figure 4) as no credits are required for operation. Just as in the SNCR Upgrade analysis, the distribution cumulative percentage curves (Figure 5) do not overlap, indicating that at every price point, the credit purchase option is statistically favored.

Figure 2: Total NPV for SNCR Option v. Credit Purchase

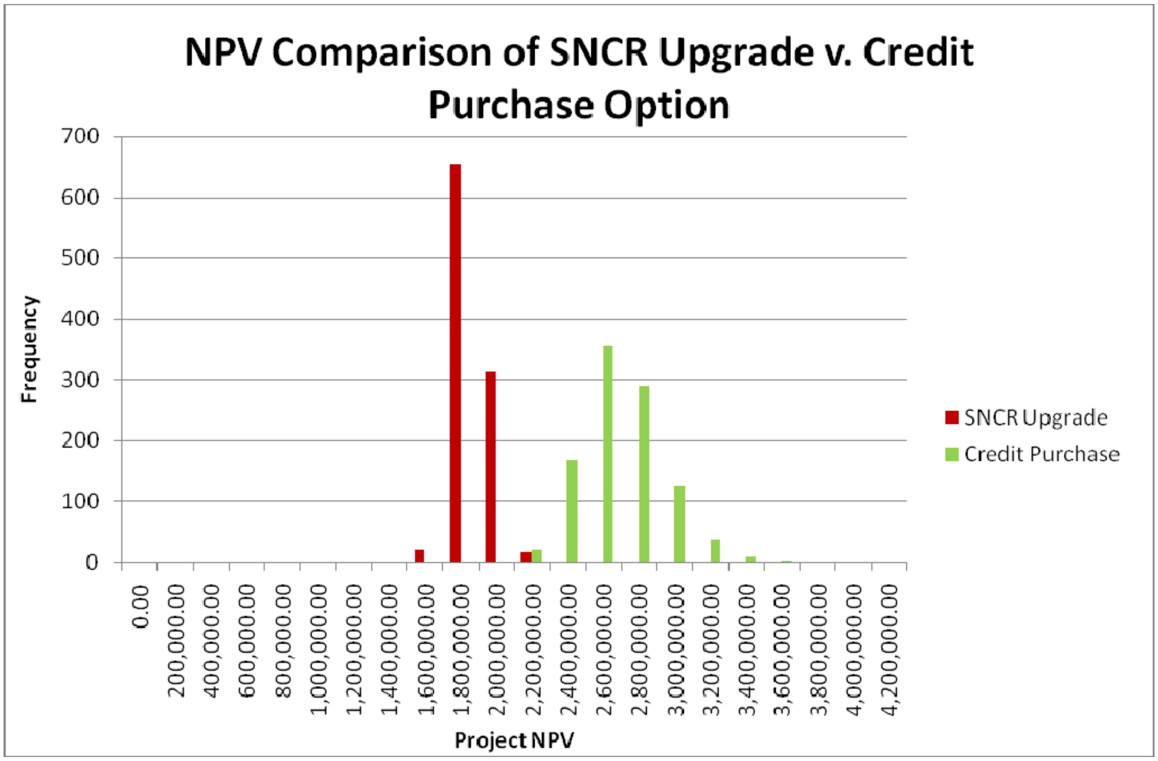


Table 10: Total NPV for SNCR Option v. Credit Purchase

Credit Price ($)	*SNCR Upgrade*	*Credit Purchase*
0.00	0	0
200,000.00	0	0
400,000.00	0	0
600,000.00	0	0
800,000.00	0	0
1,000,000.00	0	0
1,200,000.00	0	0
1,400,000.00	0	0
1,600,000.00	19	0
1,800,000.00	654	0
2,000,000.00	312	0
2,200,000.00	15	19
2,400,000.00	0	167
2,600,000.00	0	355
2,800,000.00	0	288
3,000,000.00	0	124
3,200,000.00	0	37
3,400,000.00	0	8
3,600,000.00	0	2
3,800,000.00	0	0
4,000,000.00	0	0
4,200,000.00	0	0

Figure 3: Overlap of SNCR and Credit Purchase NPV

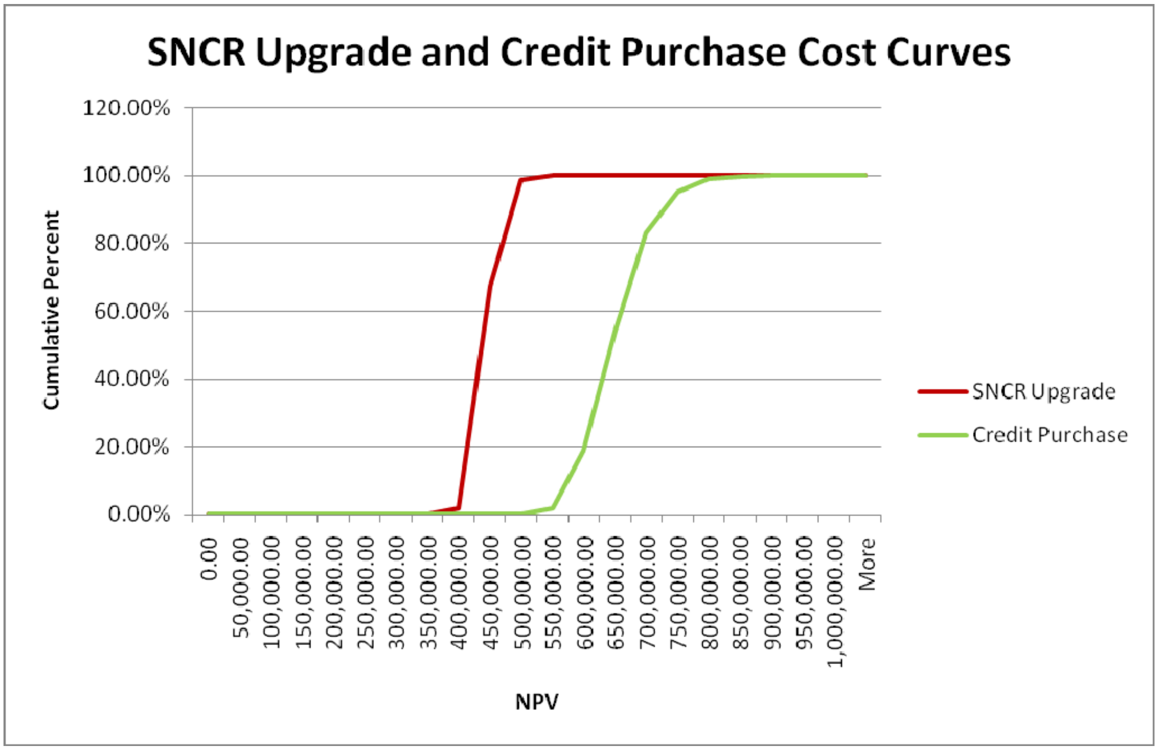


Figure 4: Total NPV for Engine Replacment v. Credit Purchase

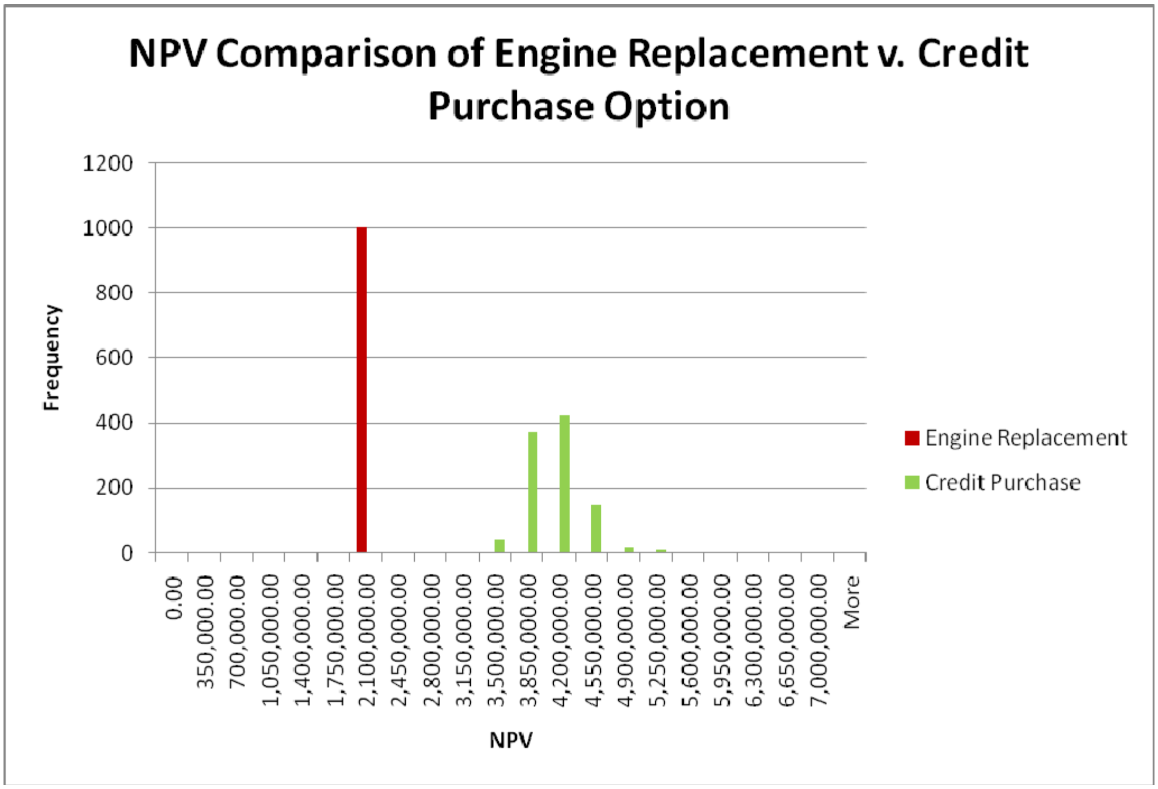
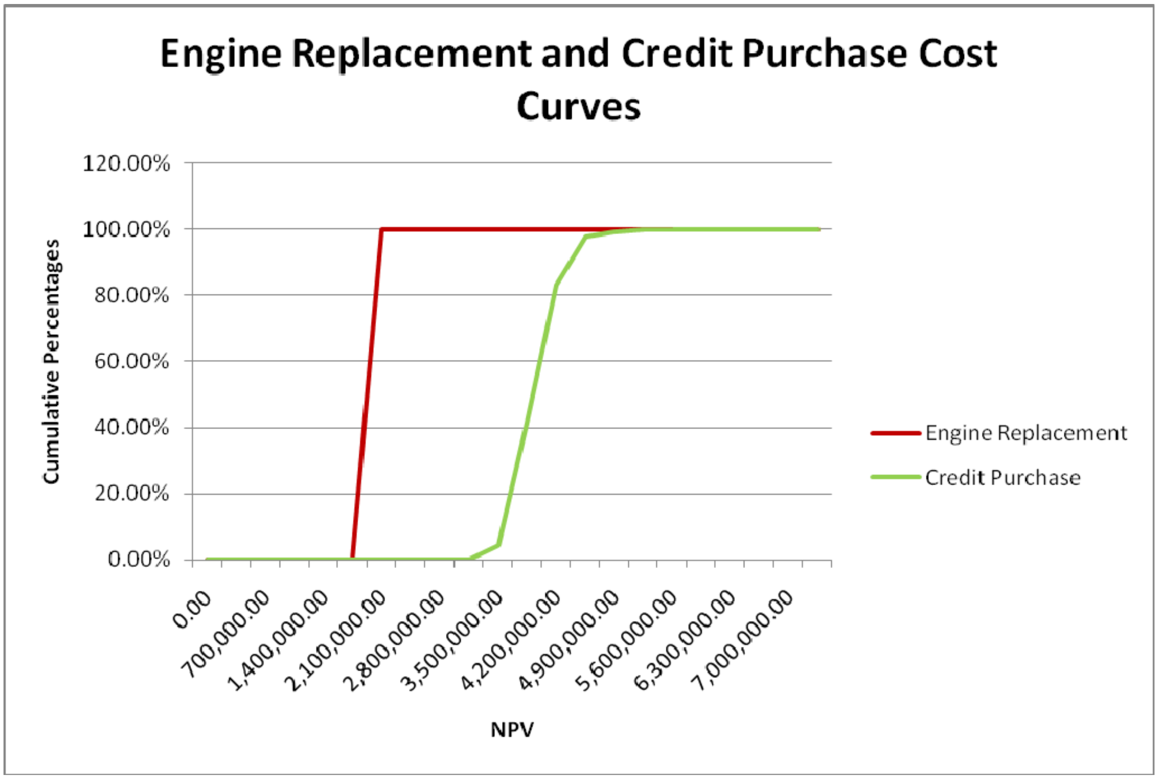


Table 11: Total NPV for Engine Replacement v. Credit Purchase

Credit Price ($)	*Engine Replacement*	*Credit Purchase*
0.00	0	0
350,000.00	0	0
700,000.00	0	0
1,050,000.00	0	0
1,400,000.00	0	0
1,750,000.00	0	0
2,100,000.00	1000	0
2,450,000.00	0	0
2,800,000.00	0	0
3,150,000.00	0	1
3,500,000.00	0	41
3,850,000.00	0	371
4,200,000.00	0	420
4,550,000.00	0	146
4,900,000.00	0	14
5,250,000.00	0	7
5,600,000.00	0	0
5,950,000.00	0	0
6,300,000.00	0	0
6,650,000.00	0	0
7,000,000.00	0	0
More	0	0

Figure 5: Overlap of Engine Replacement and Credit Purchase NPV



Section 13: Limitations of the Model

The GBM model developed is adequate in predicting credit prices with some degree of accuracy a short time into the future. This is only true, however, when there is confidence that the historical trade data is both accurately recorded and is an honest representation of actual market-based transactions. As discussed in Section 9, companies with shared interests sometimes trade emissions credits to one another at sub-market prices. Without knowing which transactions occur under these circumstances, there will always be some degree of error in the credit price simulation.

Larger factors also play a role in reducing the accuracy of the model. Economic growth in a region with a cap and trade system generally results in an increase in credit value. As companies scale up production and new firms move into the area, competition for available credits increases. Likewise, a period of economic recession, as experienced late in 2008 and throughout 2009 would most likely decrease the demand for credits, in turn reducing their value. This GBM model does not take into account broad economic indicators in the Houston-Galveston area and therefore cannot adjust the credit prices accordingly. While it may be possible to use leading economic indicators in Houston such as production orders and building permits from participating companies, a correlation between the indicators and credit prices must be established before these broad economic indicators can be taken into account.

Similarly, it is expected by administrators of the MECT program that the cost of credits required to operate a newly built, large facility may drive some of the industrial growth immediately outside the MECT program counties[32]. A manufacturing company looking to construct a new plant in the Houston area may choose a site immediately east of the MECT area (Jefferson or Hardin County) instead of assuming the additional cost of compliance. This behavior likely has little impact on credit price, but nevertheless, TCEQ metrics cannot currently track this growth immediately outside of the program area.

Section 14: Conclusions and Suggestions for Further Research

As discussed previously, the strong relationship between historical data and modeled credit prices indicates that GBM modeling is appropriate for this application. The strength of that relationship is due to a reasonably large data pool to reference, as well as some market stability from the finalized regulations. The data, however, is not robust enough to allow for predicted credit prices more than several transactions into the future.

While it is easy to conclude from the modeling that capital cost outlays plays a large role in project NPV, these cases assume that the decision about whether to upgrade or purchase credits is being made in the present time. This research does not address whether it would have been better to invest in equipment upgrades in 2002 rather than paying for eight years worth of emission credits.

In order to address this question, GBM models specific to each credit year, from 2002-2007 would have to be created. This is not difficult, but the higher volatility present in a developing market would reduce the precision of the model. This was demonstrated when comparing the statistical significance of the GBM model using 2002-2009 data versus 2007-2009 data. Additionally, some type of real option valuation would have to be considered as the equipment owner can decide at any time to still pursue the equipment upgrade option instead of continuing to invest in more emission credits. This option to change strategic direction has value and should be accounted for in the cost analysis. This research, while not without challenges, would be an appropriate way for estimating future carbon credit prices, should a formal program ever be implemented.

The fledgling carbon market would likely experience some of the same price volatility due to uncertainty that the MECT market experienced during the early years.

As time progresses and more transaction data is recorded by the TCEQ, it is likely that simulated GBM credit prices will more accurately reflect actual credit prices. Were there occasion to use this model for future applications, it is important to use the most up-to-date transaction data available. As demonstrated in selecting the 2007-2009 data sets over the 2002-2009 data sets, the model is only as good as the data it is based on[33].

Appendix A: Historical NOx Emission Allowance Trade Data

Figure A-1: 2002 Transactions

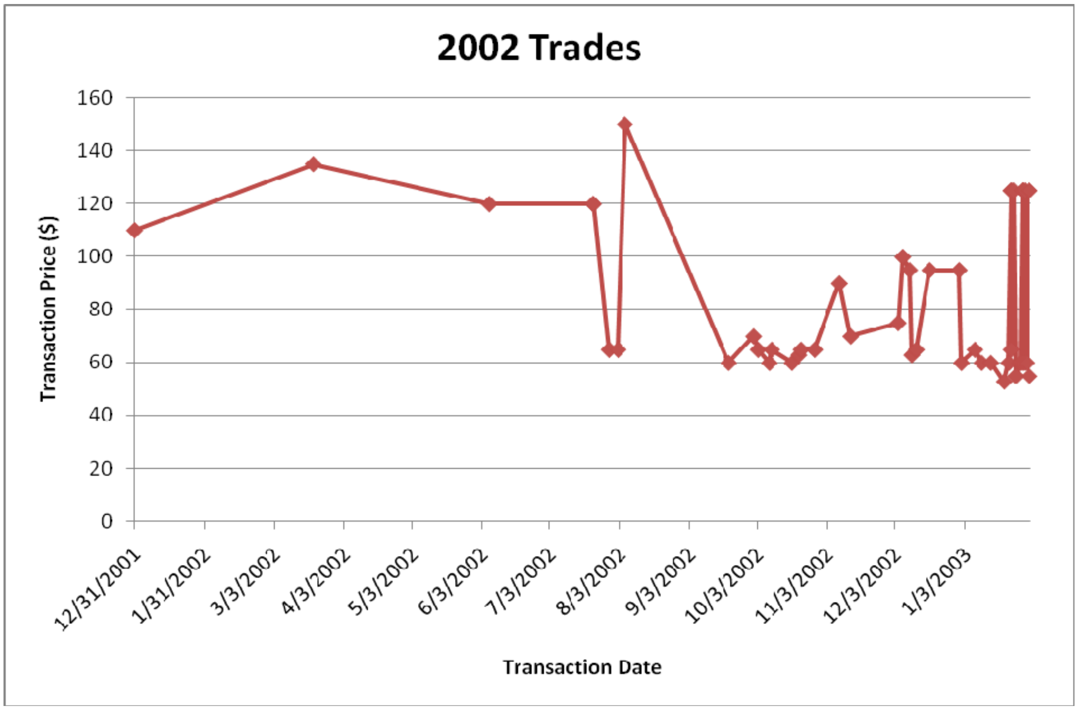


Figure A-2: 2003 Transactions

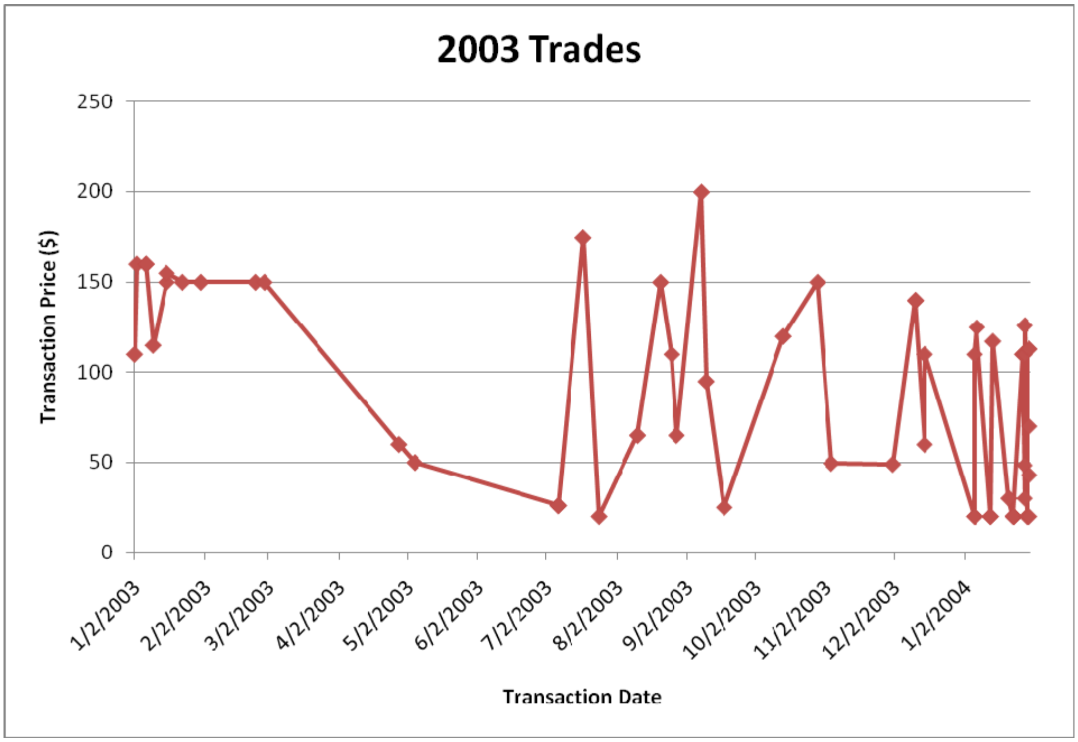


Figure A-3: 2004 Transactions

Figure A-4: 2005 Transactions

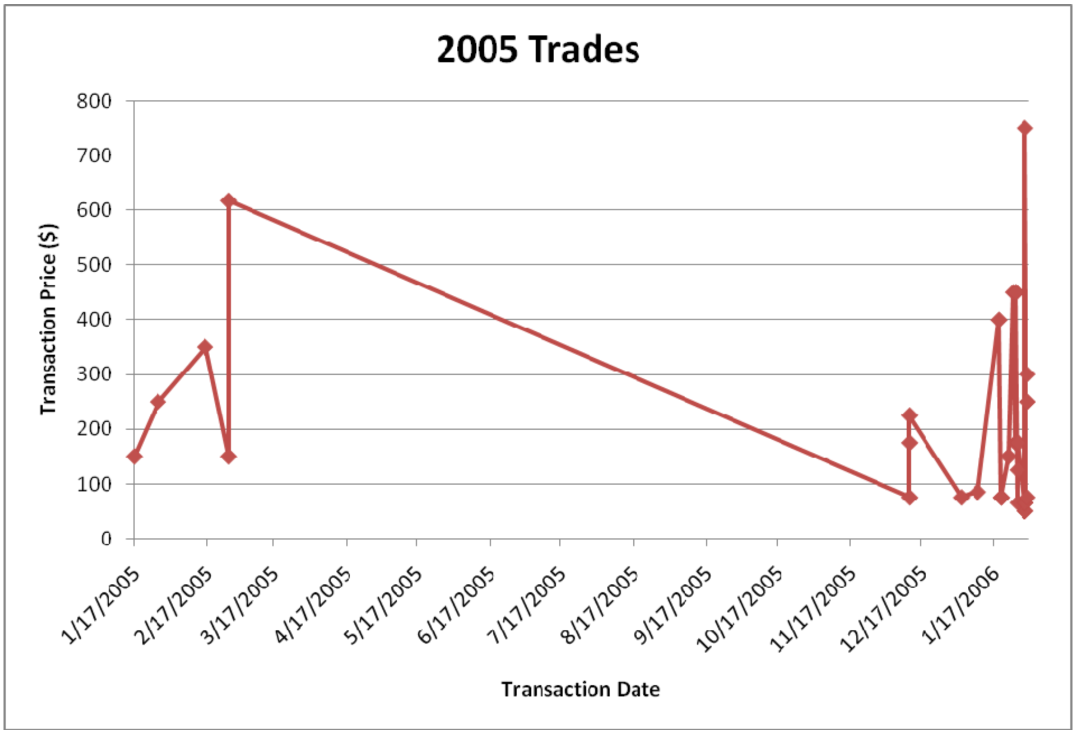


Figure A-5: 2006 Transactions

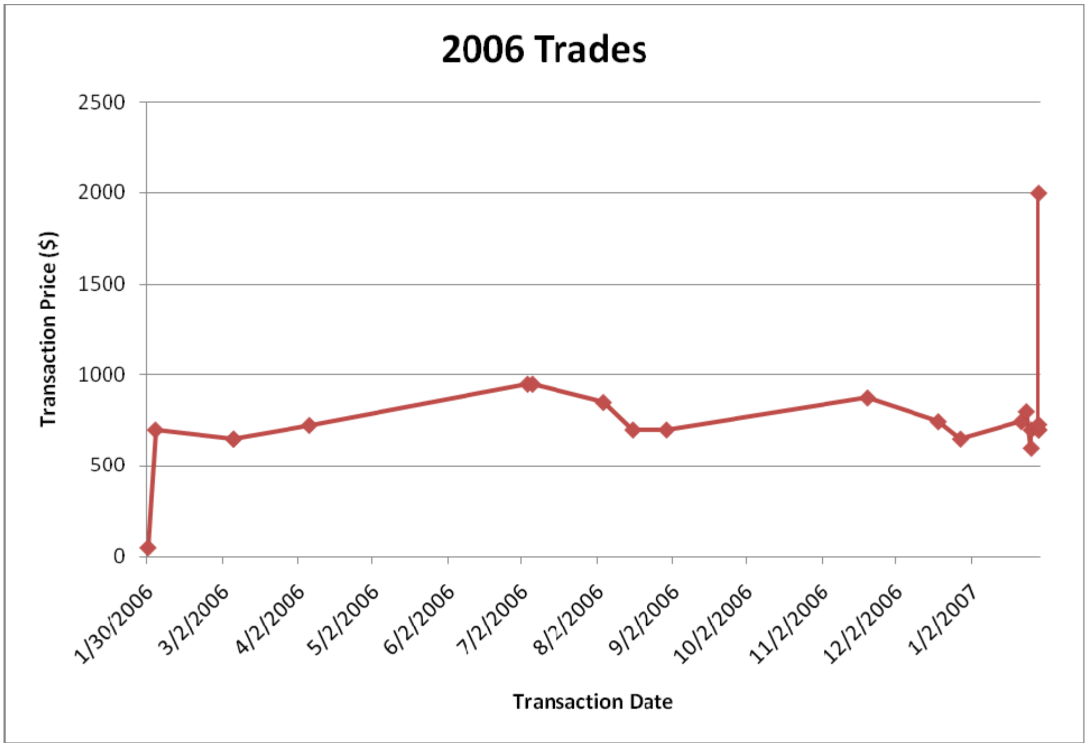
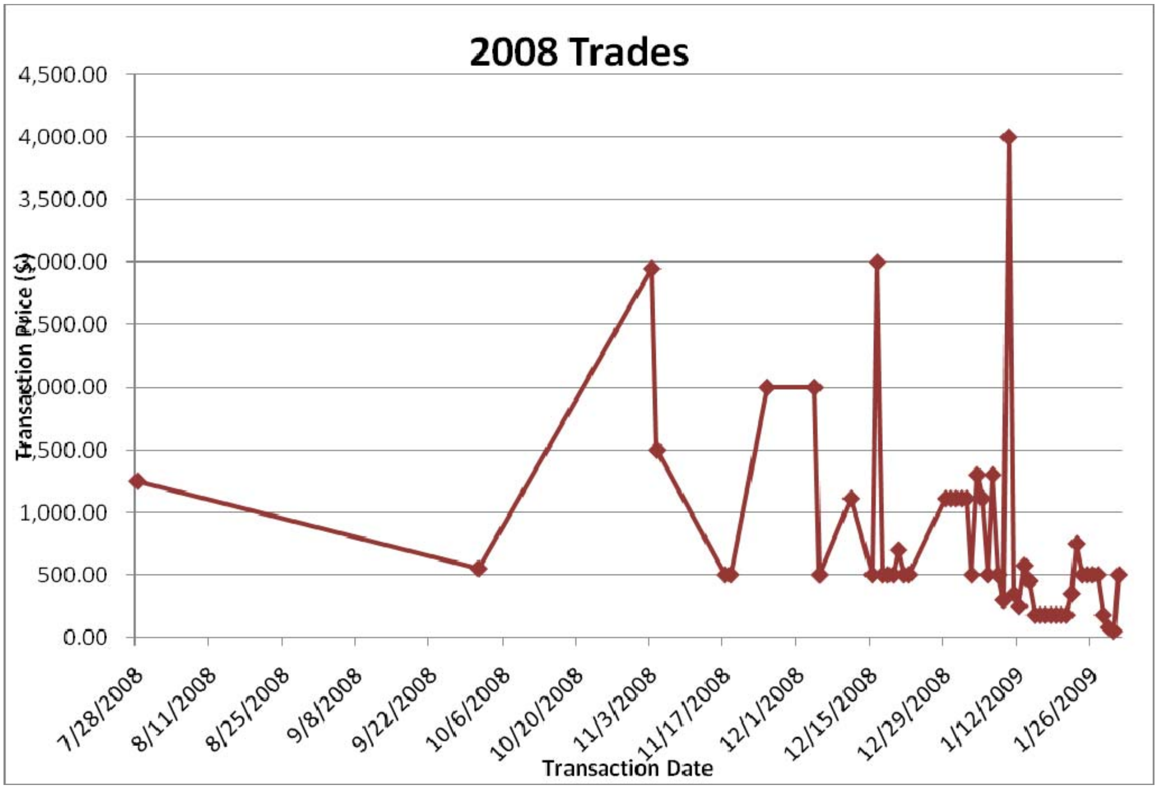


Figure A-6: 2007 Transactions

Figure A-7: 2008 Transactions



Appendix B: Simulated Results of Quarterly Sampling (2007-2009)

Figure B-1: Period 1 Modeled Results

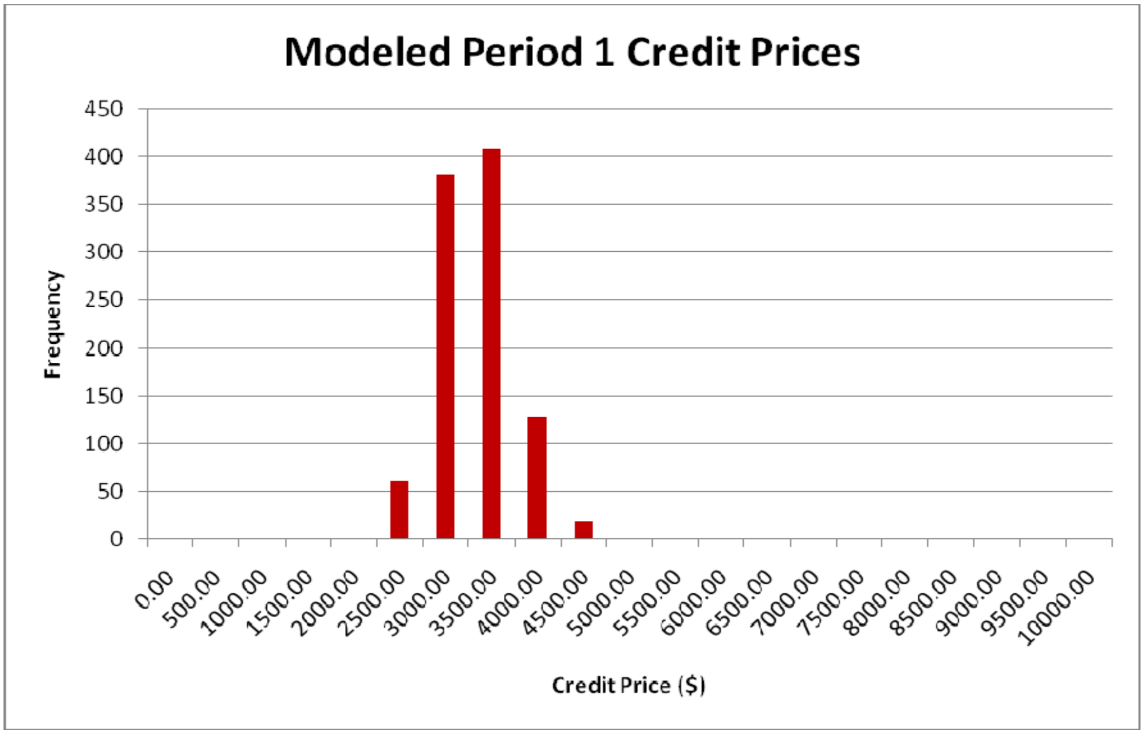


Figure B-2: Period 2 Modeled Results

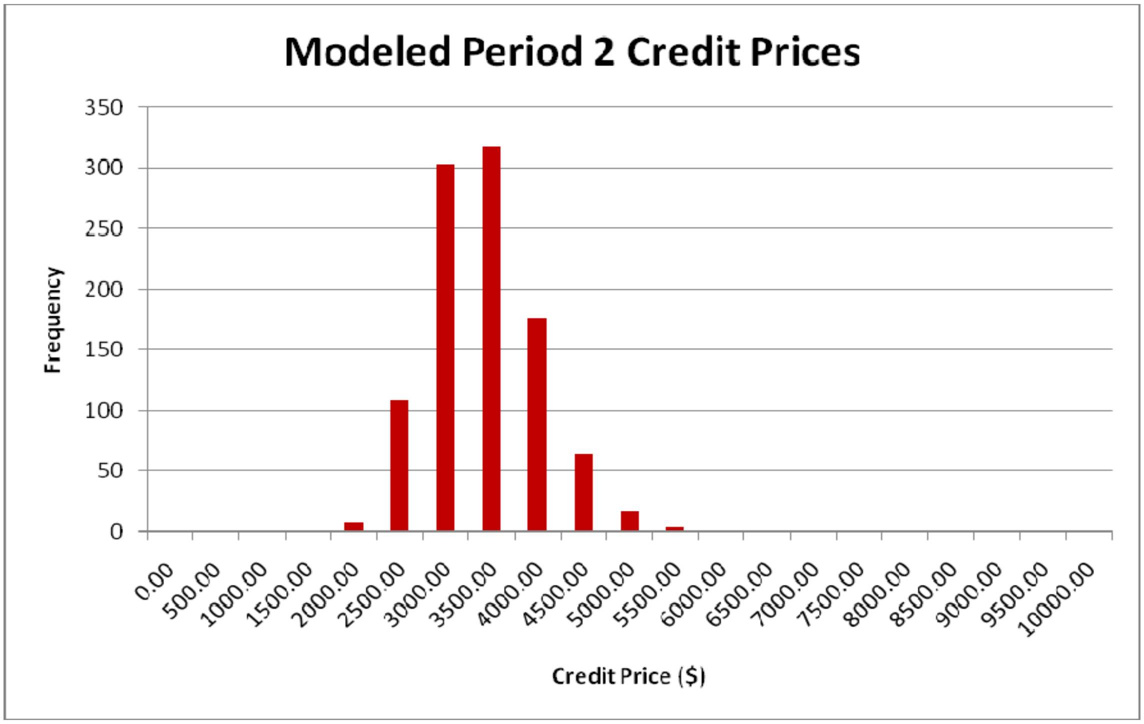


Figure B-3: Period 3 Modeled Results

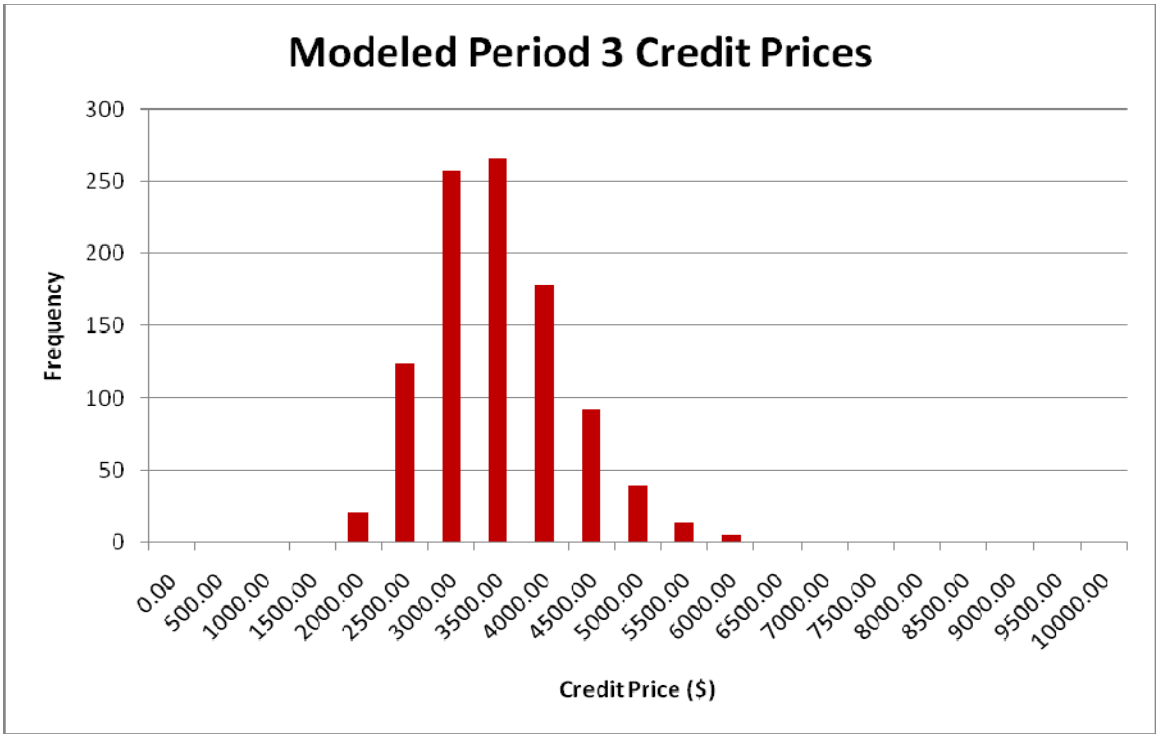


Figure B-4: Period 4 Modeled Results

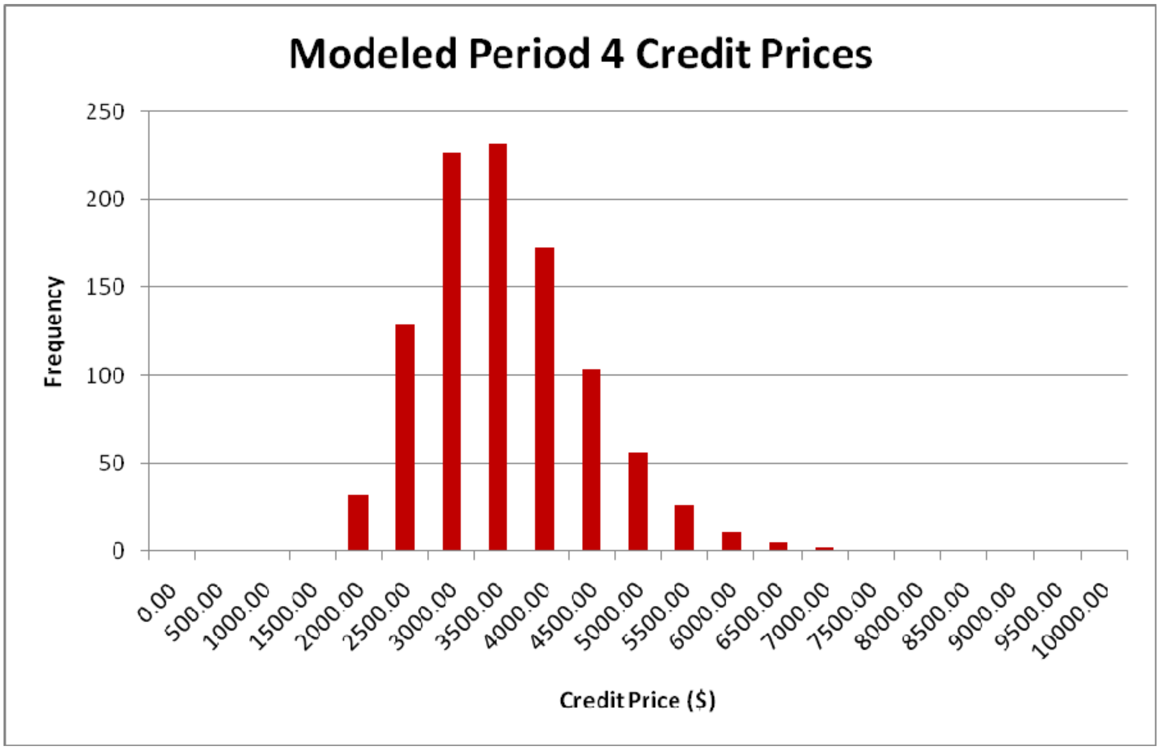


Figure B-5: Period 5 Modeled Results

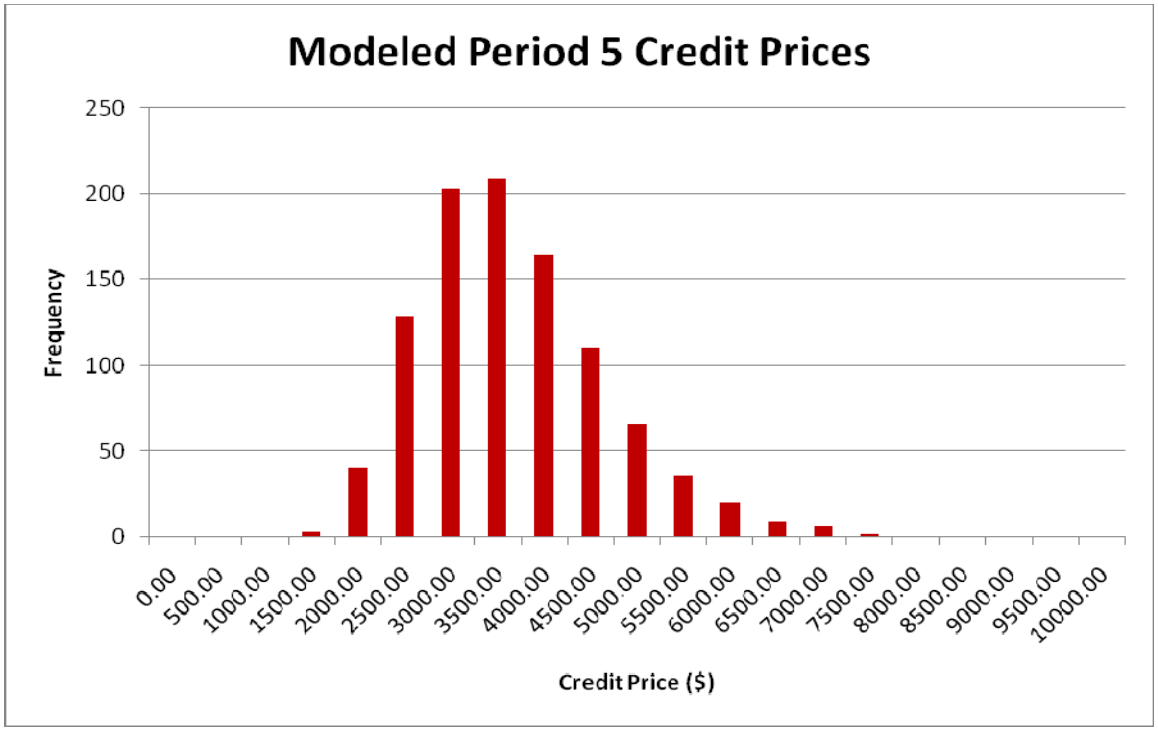


Figure B-6: Period 6 Modeled Results

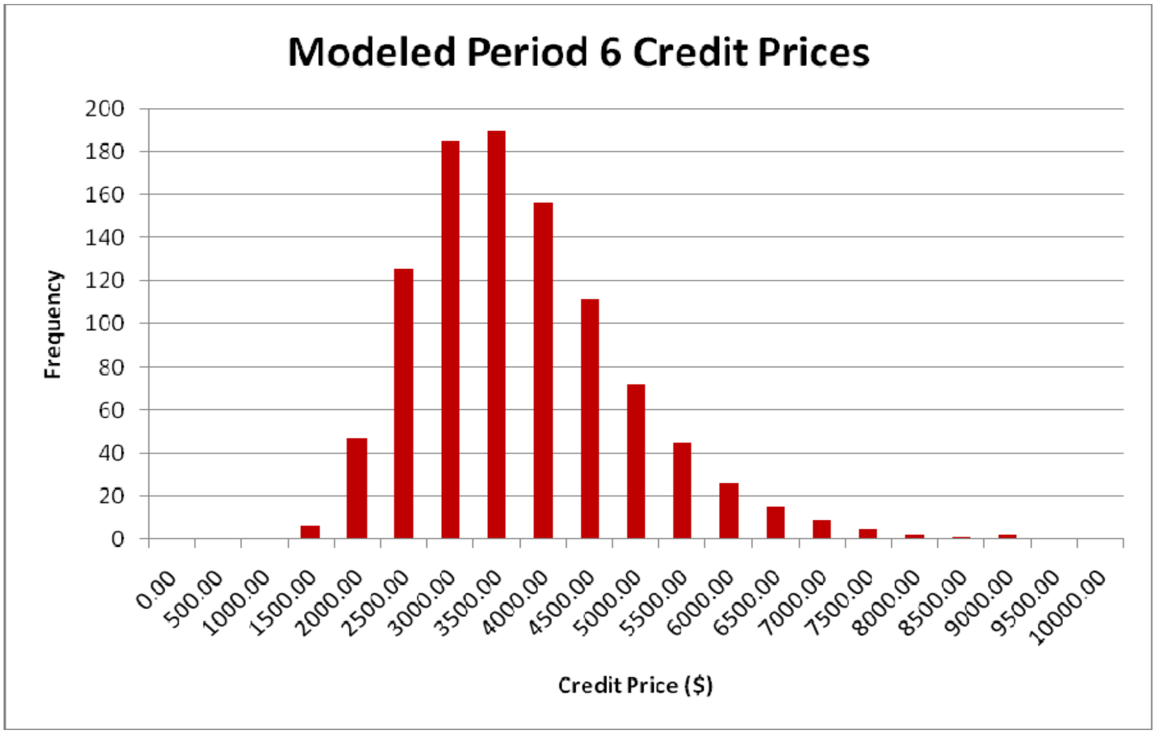


Figure B-7: Period 7 Modeled Results

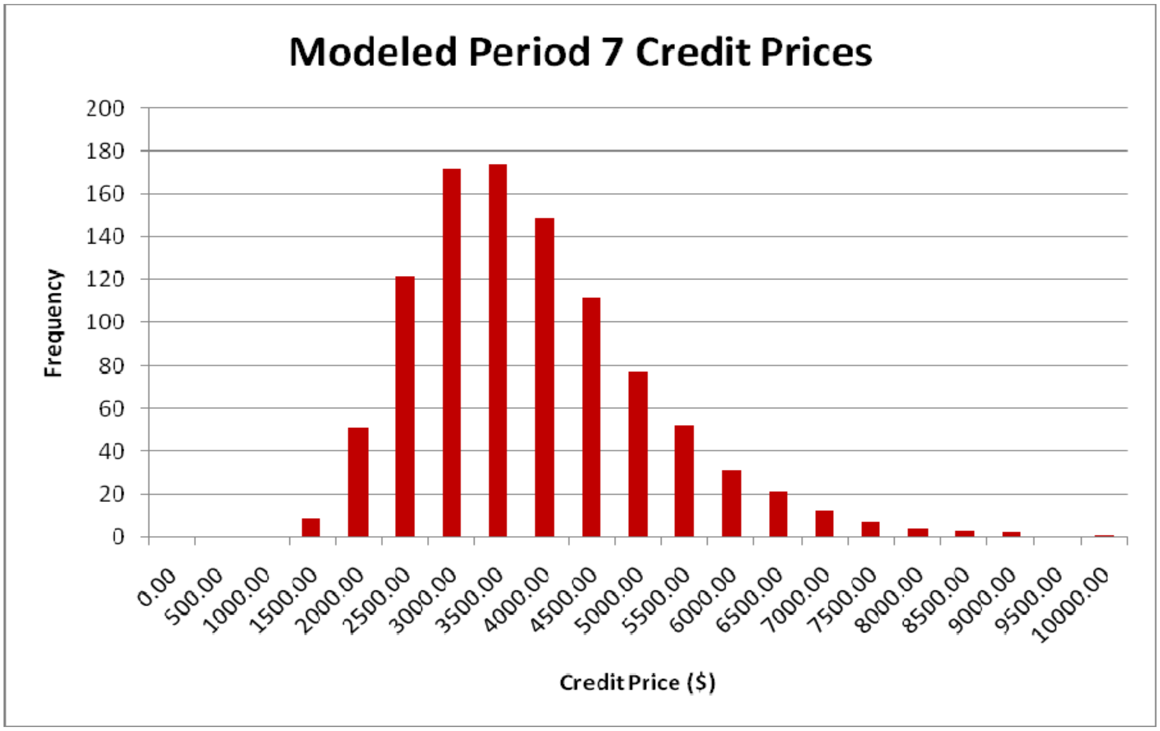


Figure B-8: Period 8 Modeled Results

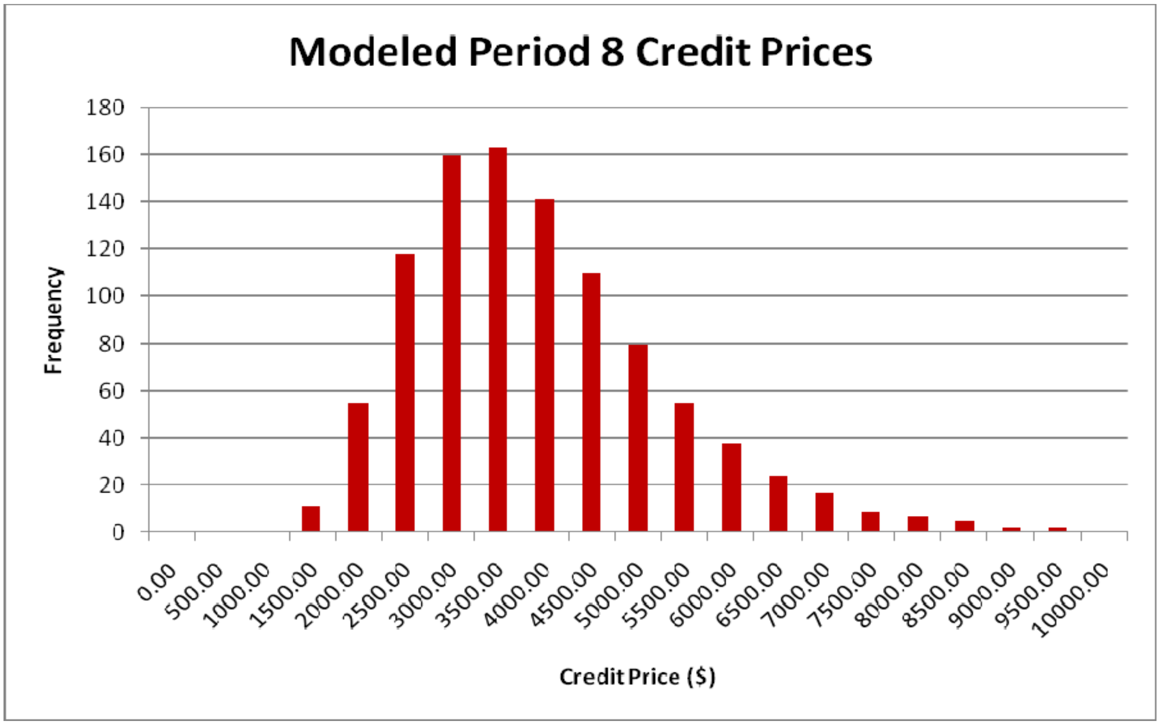


Figure B-9: Period 9 Modeled Results

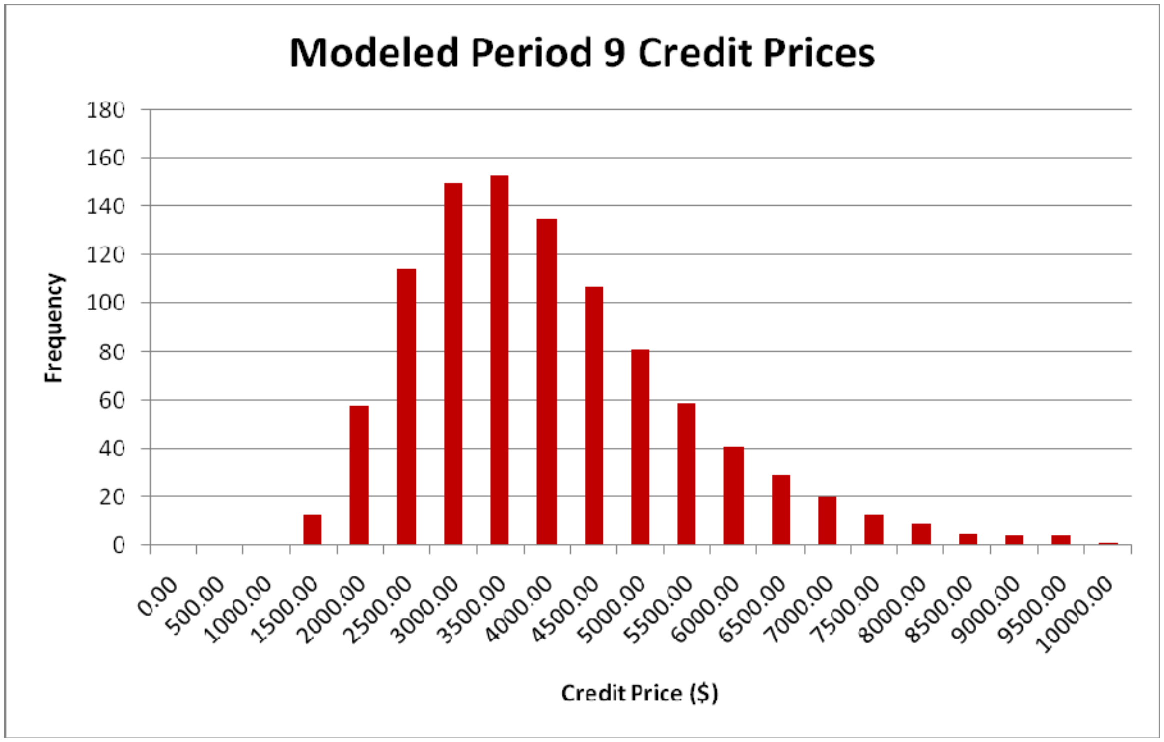
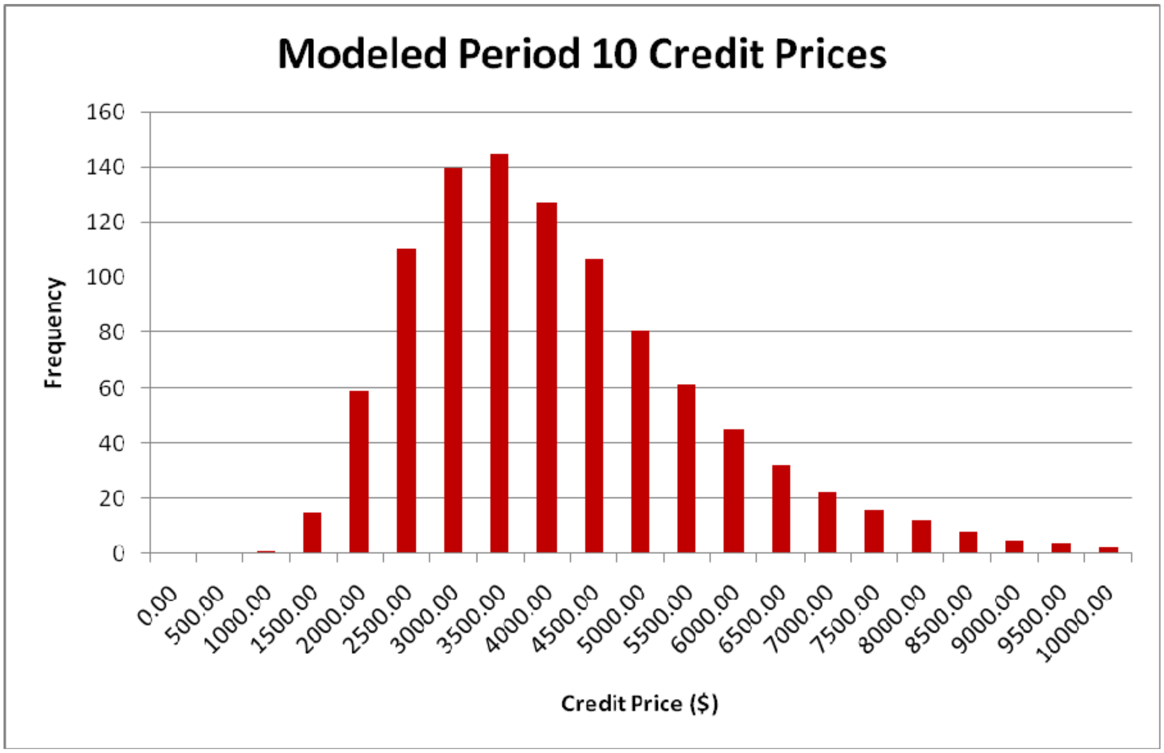


Figure B-10: Period 10 Modeled Results



Appendix C: GBM Models

Table C-1: Case 1 Boiler SNCR Upgrade

Model Inputs		
Volatility	Drift	Initial Credit Price
0.13	0.02694	3000

No. of Credits Needed	8.76	Capital investment	95000
Discount rate	5.00%	O&M Costs	10000

Period	0	1	2	3	4	5	6	7	8	9	10
Credit Price	3,000.00	3,228.13	3,738.44	3,275.37	2,566.79	4,599.59	4,365.20	3,166.41	6,156.24	2,477.29	3,609.29
Net Cost	131,280.00	38,278.41	42,748.74	38,692.20	32,485.07	50,292.45	48,239.15	37,737.76	63,928.65	31,701.04	41,617.42
NPV	131,280.00	36,455.62	38,774.37	33,423.78	26,725.55	39,405.45	35,996.80	26,819.52	43,269.43	20,434.77	25,549.48

Total NPV 458,134.77

Table C-2: Boiler Credit Purchase

Model Inputs

Volatility	Drift	Initial Credit Price
0.13	0.02694	3000

No. of Credits Needed	21.90	Capital investment	0
Discount rate	5.00%	O&M Costs	0

Period	0	1	2	3	4	5	6	7	8	9	10
Credit Price	3,000.00	3,228.13	3,738.44	3,275.37	2,566.79	4,599.59	4,365.20	3,166.41	6,156.24	2,477.29	3,609.29
Net Cost	65,700	70,696	81,872	71,731	56,213	100,731	95,598	69,344	134,822	54,253	79,044
NPV	65,700	67,330	74,260	61,964	46,246	78,925	71,337	49,282	91,253	34,972	48,526

Total NPV	689,794

Table C-3: Engine Replacement Option Model

Model Inputs

Volatility	Drift	Initial Credit Price
0.13	0.02694	3000

No. of Credits Needed	-3.14	Capital investment	450000
Discount rate	5.00%	O&M Costs	250000

Period	0	1	2	3	4	5	6	7	8	9	10
Credit Price	3,000.00	2,913.25	3,116.67	2,805.53	3,163.87	2,269.83	4,576.35	5,496.45	4,507.46	4,075.72	3,609.29
Net Cost	690,580	240,852	240,214	241,191	240,065	242,873	235,630	232,741	235,847	237,202	238,667
NPV	690,580	229,383	217,881	208,350	197,502	190,297	175,831	165,405	159,630	152,903	146,521

Total NPV 2,534,283

Table C-4: Engine Credit Purchase Model

Model Inputs		
Volatility	Drift	Initial Credit Price
0.13	0.02694	3000

No. of Credits Needed	31.80	Capital investment	0
Discount rate	5.00%	Variable cost per ton	250000

Period	0	1	2	3	4	5	6	7	8	9	10
Credit Price	3,000.00	2,913.25	3,116.67	2,805.53	3,163.87	2,269.83	4,576.35	5,496.45	4,507.46	4,075.72	3,609.29
Net Cost	345,400	342,641	349,110	339,216	350,611	322,181	395,528	424,787	393,337	379,608	364,776
NPV	345,400	326,325	316,653	293,027	288,449	252,437	295,149	301,888	266,226	244,699	223,941
Total NPV	3,154,194										

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Vita

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