Reexamining Metallgesellschaft's Hedging Policy: Does Anything Beat a One-For-One Hedge Ratio?

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There has been significant debate surrounding Metallgesellschaft's derivatives based fixed-price marketing strategy. Most of this debate relates to Metallgesellschaft's choice to use a one-for-one hedge ratio instead of an alternative hedge ratio optimized for risk management. I contribute to this discussion by reexamining the hedging strategy of Metallgesellschaft and use the Test for Superior Predictive Ability to determine whether any hedge ratio less than one outperforms the one-for-one hedge utilized by Metallgesellschaft.

Introduction

This paper is motivated by the debate surrounding appropriate hedging ratios and the hedging strategy implemented by Metallgesellschaft. I will examine the one-for-one hedge ratio used by Metallgesellschaft and answer the question of whether any hedge ratio less than one is able to outperform it. I will model the returns on a portfolio of monthly spot and future prices for heating oil and unleaded gasoline using hedge ratios from 0 to 1 in increments of 0.05. The returns that are obtained from using different hedge ratios will be treated as errors, and loss functions will be used to determine model losses for each hedge ratio. The Test for Superior Predictive Ability will then be used to compare the losses from alternative hedge ratios to the benchmark losses of a one-for-one hedge.

Metallgesellschaft

Metallgesellschaft AG (MG) was a German conglomerate that operated from 1881 until it was restructured in 2000. As its name would suggest, MG originally started as a metal company, but throughout its lifetime MG grew to be comprised of over 250 different subsidiaries operating in a variety of sectors ranging from metals to finance (Mello & Parsons, 1995; Culp & Miller, 1995a). One MG subsidiary, Metallgesellschaft Refining and Marketing (MGRM), operated in the United States and sold petroleum products such as heating oil and unleaded gasoline. MGRM came to prominence in the mid-1990s after it experienced historic losses from a derivatives-backed marketing strategy. Estimates of MGRM's gross losses have been cited to range from 1 billion to as high as 1.3 billion (Pirrong, 1997; Culp & Miller, 1995a; Bollen & Whaley, 1998). As a result, the manner in which MGRM executed its derivatives-backed marketing strategy has been a topic of much debate in academia and has been used as a case-study in risk management curricula.

MGRM Fixed-Price Marketing Strategy

MGRM recognized that independent petroleum retailers were faced with a choice between exposing themselves to highly volatile petroleum spot prices they relied upon for their supply, or entering into supply contracts that were priced higher than what MGRM assessed it could provide (Mello & Parsons, 1995). In late 1991, MGRM hired Arthur Benson to retool its strategy for marketing petroleum products (Culp & Miller, 1995a). Benson and his team devised a strategy whereby MGRM sold fixed-price contracts for unleaded gasoline and heating oil to retailers for monthly delivery at terms of 2, 5, or 10 years, with a small portion of contracts having an exit clause which would settle early if the futures price rose above a pre-determined exit price. By December of 1993, MGRM had sold fixed-price contracts on their petroleum products for approximately 160 million barrels (Bollen & Whaley, 1998). MGRM employed a one-for-one stack-and-roll hedge utilizing short-term futures and swaps to synthetically store petroleum. To execute the stack-and-roll hedge, MGRM purchased short-term futures or swaps for the entire 160 million barrels of petroleum products it was committed to delivering in its fixed-priced contracts. Every month thereafter, MGRM would roll into a sufficient number of the next short-term future or swap contracts to cover their entire remaining fixed-price commitments.

MGRM's stack-and-roll hedge was designed to take advantage of frequent backwardation in the term-structure of petroleum futures. Backwardation exists when the price of a commodity for delivery at a future date is lower than the spot price of the underlying asset; in backwardation the basis is positive. Conversely, when the basis is negative, the market is said to be in contango. During periods of backwardation MGRM would earn a positive roll-return on its stack-and-roll hedge due to the convergence of the futures price and spot price of the underlying as the futures contracts approached maturity, and negative roll-return on their hedge during periods when the market was in contango.

In the Fall of 1993 when the market swung from backwardation to contango Benson and his team began to experience pressure from management as a result of their hedging strategy (Culp & Miller, 1995a). These pressures came about from increased cash requirements to meet margin calls resulting from daily marking-to-market of their position in futures contracts. When the market went from backwardation to contango, the price for the near-month futures contracts increased relative to the spot price and MGRM was then required to pay a premium for their synthetic storage. Due to the extent the market was in contango and the size of MGRM's position in the futures market, by December 1993 NYMEX began to charge MGRM 'supermargin' on their futures position (Culp & Miller, 1994). In addition to the significant cash demands created by the new margin requirements, some of MGRM's counterparties in their OTC derivatives contracts began to terminate their derivatives contracts (Culp & Miller, 1994). Following these actions, MG AG took control of MGRM and began to unwind its derivatives hedge, causing MGRM to realize their hedging losses to the amount of 1.3 billion (Culp & Miller, 1994).

Debate on Appropriate Hedging

In the aftermath of MGRM's decision to end their fixed-price marketing program, and following revelations of the extent of its losses, a debate about proper execution of MGRM's derivatives-based hedging strategy emerged. This debate centered on the appropriate hedge ratio MGRM should have used in the futures market to achieve its objective. Opponents of MGRM's strategy argue that a one-for-one hedge was well above what was required, while proponents argue that MGRM's one-for-one hedge ratio was well-informed and chosen intentionally. Though the debate centers around hedge ratios, at its core the debate is about MGRM's objective with their hedge, and a more general disagreement about the nature of hedging.

Opponents of MGRM's hedging strategy argue that the use of a one-for-one stack and roll hedge is not appropriate to hedge the risk for MGRM's fixed-price commitments against changes in the spot market. Papers written by Pirrong (1997), as well as Mello and Parsons (1995) argue that MGRM's one-for-one hedge was largely an act of speculation and should not be considered an exercise in hedging for risk management. In fact, Pirrong (1997) directly states, "...it is impossible to view the firm's strategy as a prudent exercise in risk management." (p. 544). Both papers from these authors take the stance that hedging is done largely to minimize exposure to risk and consider any hedge in excess of the minimum variance hedge ratio to be speculative. While it is clear that Pirrong (1997) recognizes that most firms tend to exceed the minimum variance hedge to earn higher expected returns on their hedge, it is important to recognize that he would classify this excess portion of the hedge to be speculative. In his paper, Pirrong (1997) calculates appropriate minimum variance hedge ratios to determine the degree to which MGRM was speculating and finds that MGRM took on as much as 19% - 350% more risk than necessary at times. Mello and Parsons (1995) suggest MGRM's choice to use a one-for-one stack and roll hedge is speculation disguised as a risk management strategy. Mello and Parsons (1995) argue that in addition to MGRM hedging in excess of what was required to manage risk, the use of a stack-and-roll hedge, instead of hedge that matched up more closely with the maturity of MGRM's delivery obligations such as a strip hedge, was further proof it was behaving speculatively. Ultimately Mello and Parsons (1995) agree that MG senior management were right to close the futures positions of the hedge and cut their losses before they became even worse.

Culp and Miller (1995a) are two proponents of MGRM's strategy and argue that MGRM's hedge was not speculative. They describe MGRM's hedging strategy as one of synthetic storage whereby MGRM synthetically 'store' petroleum products for future delivery in futures contracts. In times the market is backwardated this synthetic storage is cheaper, from MGRM's position, than physical storage would be (Culp & Miller, 1995a). This is because when the market is in backwardation, the spot price for petroleum products is higher than the price of the same petroleum products in the future. This indicates that the holder of the commodity earns a convenience yield in excess of the storage costs for having access to the petroleum product (Culp & Miller, 1995a). Culp and Miller (1995b) argue that synthetic storage is a form of hedging described by Holbrook Working as carrying-charge hedging. Working (1961) defines carrying-charge hedging as a type of hedging that is undertaken not to avoid risk, but to seek profit by merchants whose business it is to understand and anticipate changes in price relations. Given that MGRM's purpose was to market petroleum products to retailers, they would surely fit the description of Working's knowledgeable merchant. Culp and Miller (1995b) provide further evidence that this is the case by quoting MGRM's annual report from 1991 and 1992 in which MGRM state that they have an information advantage with regard to the basis of petroleum products due to their market presence. Instead of blaming improper hedging, Culp and Miller (1995a) suggest the failure of MGRM's strategy was likely the result of operational risk resulting from senior level managers not completely understanding MGRM's hedging strategy, seeing the increased need for cash as a precursor to failure, and deciding to unwind the hedge in futures prematurely. They argue against the idea that MGRM was experiencing problems with creditors and argue that because Deutsche Bank was the majorority shareholder for MG, funding MGRM's hedging strategy should not have been problematic (Culp & Miller, 1995b).

Bollen and Whaley (1998) contribute to the debate by seeking to answer the question of what would have happened had MGRM continued with their fixed-price marketing strategy and left their hedge in place. Using monthly futures prices from 1985 - 1991 they estimated a model of the basis dynamics for heating oil and unleaded gasoline and then used Monte Carlo simulation to generate 5000 different price paths for the 10-year period from November 1991 - November 2001 (Bollen & Whaley, 1998). Using information from MGRM on the number and type of their fixed-price contracts, as they stood in December 1993, Bollen and Whaley (1998) were then able to manually calculate MGRM's profits and losses by using different hedge ratios ranging from 0 to 1 in increments of 0.05 for each price path generated in the Monte Carlo simulation. Their results showed that that 99.9% of the time, MGRM's marketing and hedging strategy was profitable regardless of the hedge ratio used; meaning MGRM's biggest mistake was putting an end to their marketing program (Bollen & Whaley, 1998). Additionally, they found that with one-for-one hedge ratio there was a 33% chance of a cash position of - $1 billion at some point in time, an expected profit of $4 billion, and a maximum profit of over $8 billion over the 5000 different trials (Bollen & Whaley, 1998).

Method

Calculation of Returns

I used monthly spot prices and prices for the next month futures contracts for heating oil and unleaded gasoline over the sample period (November 1991 - November 2001). MGRM's fixed-price contracts represent a future commitment it is short. If MGRM did not hedge their short positions at all, it would be subject to spot price changes and the single-period return under this assumption would be:

$$r_{t+1} = -\Delta S_{t,t+1}$$

Where $\Delta S_{t,t+1}$ is the change of the spot price from time t to 1-period into the future and the negative sign indicates the short position. In this situation, MGRM would only earn a positive return on its fixed-price contracts when the spot price decreased from time t to time t + 1.

But MGRM does hedge its short position in the futures market. In order to account for MGRM's long position, let γ represent the hedge ratio MGRM used for their long position in the futures market. In a one-for-one hedge $\gamma = 1$ and MGRM's continuously compounded return would simply be the difference in the change in the log price of MGRM's future position and the log price of the change in the spot price of the commodity. More generally:

$$r_{p_{t,t+1}} = \gamma \Delta F_{t,t+1} - \Delta S_{t,t+1}$$

Where r_p represents a portfolio of long and short positions in either heating oil or unleaded gasoline.

Modeling MGRM's returns in this way is consistent with a carrying-charge / synthetic storage hedge. This is because $\gamma \Delta F_{t,t+1} - \Delta S_{t,t+1}$ is the return for trading the basis for the portfolios of petroleum products in a pairs trading framework.

Selection of Loss Functions

In order to use the Test for Superior Predictive Ability to compare different hedge ratios against the benchmark one-for-one hedge used by MGRM, the returns must first be converted to losses. Results from the SPA test are directly dependent upon the loss function used, so I opted to use three different loss functions to ensure that that the results were robust. Additionally, I set the error $e = -r_{p_{t,t+1}}$ so that negative returns are more easily penalized with standard loss functions, particularly Piecewise Linear (Lin-Lin).

I used three different loss functions:

Squared Error

$$L(e) = e^2$$

Absolute Error

$$L(e) = \mid e \mid$$

Piecewise Linear (Lin-Lin):

$$L(e) = \begin{cases} -a(1-\alpha)e & if \;\; e \leq 0 \\ a\,\alpha\,e & if \;\; e > 0 \end{cases} \qquad for\; a > 0$$

Both positive and negative errors are penalized the same in SE and AE loss functions. These loss functions impose a loss based on the difference between the predicted value and the actual value. The Lin-Lin loss function penalizes the error differently dependent upon the sign of the error. With Lin-Lin, positive errors (negative returns) are penalized dependent upon the a and α parameters. The a parameter can be viewed as a means to scale the losses, for the purposes of this study I set $a = 1$. I set the parameter $\alpha = 0.99$ so that positive errors (negative returns) are weighted at 99% their value and negative errors (positive returns) are scaled to only be weighted 1% their value. From MGRM's perspective it makes sense to set the parameters of the Lin-Lin loss function in this manner. MGRM is hedging in order to earn a positive roll-return and would surely not want to penalize these "errors" similarly to ones of the opposite sign.

The Test for Superior Predictive Ability

I utilized the Test for Superior Predictive Ability (SPA) developed by Hansen (2005) to determine whether any alternative hedge ratio is able to outperform a one-for-one hedge. The SPA test proposed by Hansen (2005) expands upon the earlier Reality Check for Data Snooping developed by White (2000) and has increased power gained by studentizing the SPA test statistic and utilizing a sample-dependent null distribution. The SPA test is designed to compare the losses from a benchmark model to losses obtained from a set of alternative models and is then able to determine whether the benchmark model was significantly outperformed by any of the alternatives. The below explanation of the Test for Superior Predictive Ability follows from Hansen (2005), Hansen and Lunde (2005), and Sheppard (2014).

To conduct the SPA test, the loss differentials at time t are defined as

$$\delta_{k,t} = L(y_{t-h}, \hat{y}_{t-h,BM|t}) - L(y_{t-h}, \hat{y}_{t-h,k|t}), \qquad for\ \ models\ \ k = 1, ..., m$$

where $\hat{y}_{t-h,BM|t}$ are the predictions from the benchmark model. The loss differentials at time t can then be put into a vector $\boldsymbol{\delta_t} = (\delta_{1,t}, ..., \delta_{m,t})'$, with $\boldsymbol{\mu} = E(\boldsymbol{\delta_t})$, and the null-hypothesis for the SPA test is:

$$H_0 : \boldsymbol{\mu} \leq 0$$

The null hypothesis states that the expected value of the loss-differentials at a given time t will be less than or equal to 0 when losses from the models are greater than or equal to the losses from the benchmark.

The test statistic T^{SPA} is defined as:

$$T^{SPA} = max_{j=1,\ldots,m}\left(\frac{\bar{\delta}_j}{\sqrt{\hat{\omega_j}^2/T}}\right)$$

As previously mentioned, one of the ways in which the SPA test differs from the Reality Check is through the studentization of the test statistic. This is achieved by dividing the average loss differential for a model by: $\hat{\omega_t}^2$, an estimate of the long-run variance of $\bar{\delta}_j$ and T, which is the total number of time periods in the sample. I employed the method used by Sheppard (2014) to calculate at the estimate of $\hat{\omega}_t{}^2$:

$$\hat{\omega_t}^2 = \hat{\gamma_{j,0}} + 2\sum_{i=1}^{T-1} \kappa_i \gamma_{j,i}$$

$\hat{\gamma_{j,0}}$ is the variance of $\bar{\delta}_j$

$\hat{\gamma_{j,i}}$ is the auto-covariance of $\delta_{j,t}$

and

$$\kappa_i = \frac{T-i}{T}(1-\frac{1}{W})^i + \frac{i}{T}(1-\frac{1}{W})^{T-i}$$

which weights the auto-covariances and uses the window length (W) input in the stationary bootstrap.

Defined in this way, T^{SPA} is the maximum studentized loss differential over the time period of interest for all models. After T^{SPA} has been found, the stationary bootstrap is used to resample the loss differentials.

The stationary bootstrap is a resampling algorithm that can be used to construct a new sample from certain time-series data and is used to prevent the problem of data snooping. To execute the stationary bootstrap, a probability value assigned as $1/W$ where W is the window-length used in the stationary bootstrap. This probability can be thought of as the probability of a jump to a new randomly selected index position. The algorithm begins at a randomly selected index position. Prior to each movement a number between 0 and 1 is randomly drawn, if this number is less than the jump probability ($1/W$) then a new index position is randomly chosen, if the number is greater than the jump probability the algorithm moves forward sequentially in the index. The algorithm notes the index values used as it moves through the required number of iterations and these index values are then used to construct a new sample from the original data.

After resampling with the stationary bootstrap, the bootstrap sample $\delta^{\star}_{b,t}$ is created and a new test-statistic $T^{\star SPA}_{s,b}$ is calculated:

$$T^{\star SPA}_{s,b} = max\left(\frac{T^{-1}\sum_{t=R+1}^{T}\delta^{\star}_{j,b,t} - I^{s}_{j}\bar{\delta}_j}{\sqrt{\hat{\omega}^2_j/T}}\right), \quad s = u, c, l$$

and

$$I^{u}_{j} = 1 \ , \ I^{c}_{j} = \frac{\bar{\delta}_j}{\sqrt{\hat{\omega}^2_j/T}} > -\sqrt{2ln(ln(T))} \ , \ I^{l}_{j} = \bar{\delta}_j > 0$$

These indicator functions correspond to the three different p-values that are obtained from executing the SPA test. SPA_u provides an upper bound, SPA_l providing a lower bound, and SPA_C provides a consistent estimate of the true p-value (Hansen-Lunde, 2005).

$T^{\star SPA}_{s,b}$ is created for all of the bootstrapped samples and each indicator function. It is the maximum of the studentized differences between the model specific average loss differential of the bootstrapped sample and, dependent on the indicator function, the average model specific loss differential from the original sample.

The p-values are then calculated as the percentage of the bootstrapped samples where $T^{\star SPA}_{s,b} > T^{SPA}$:

$$p - value_s \;=\; \frac{1}{B}\sum_{b=1}^{b} I[T^{\star SPA}_{s,b} > T^{SPA}], \qquad s = u, c, l$$

Data and Results

Data

The data used in this study are prices for monthly spot and front-month futures contracts in dollars per gallon from January 1988 - November 2001 on approximately the 22nd day of every month retrieved from U.S. Energy Information Administration (n.d. a) and U.S. Energy Information Administration (n.d. b). The 22nd was used because that is when futures contracts typically expire and is used in all instances except for when the 22nd falls on a day when the markets are closed. In such cases, the closest day prior to the 22nd for which there is information is used. These data were then divided into three time periods: the period from January 1988 - November 1991, which takes place prior to the implementation MGRM's marketing strategy; the period November 1991 - January 1994, the period in which MGRM was executing their strategy until their hedge was unwound;

and the period from November 1991 - November 2001, which represents the 10-year period for which MGRM would have had delivery commitments for fixed-price contracts it sold. The 10-year period from December 1991 - November 2001 is the sample period used for this study.

January 1988 - November 1991

For the nearly three-year period preceding the implementation of MGRM's hedging strategy, January 1988 – November 1991, next-month futures contracts for heating oil were in backwardation 41% of months and unleaded gasoline was in backwardation 65% of months (Fig.1). MGRM's hedging strategy was based on belief in its ability to recognize arbitrage opportunities that exist when these markets are in backwardation and time their hedge positions accordingly. Included in Table 1 are descriptive statistics for this period for heating oil and unleaded gasoline showing that the mean is slightly greater than the median and both are approximately zero. Additionally, the maximum value of heating oil and unleaded gasoline are \$0.11 and \$0.07 respectively, with a minimum value of -\$0.02 for both. The distribution for the basis relationships of these commodities can be seen in Fig 2. As suggested by the descriptive statistics, the distribution for the basis of both commodities during this time period is right-skewed and Fig.7 shows that all outliers for the basis are greater than zero. This suggests that if MGRM were looking backward it is not unreasonable to expect to earn a positive non-zero roll-return in most months assuming the basis behaved similar to how it has historically.

November 1991 - January 1994

MGRM executed their hedging strategy from November 1991 until their futures positions were closed around December of 1993. As can be seen in Fig. 3, heating oil and unleaded gasoline were in contango the majority of the time and only experienced backwardation in 15% and 22% of months. Information in Table 1 and Fig. 4 show the distributions of the bases during this time period; both have a mean and median below zero and are slightly left-skewed. Of the two, unleaded gasoline experienced the most significant drop in basis and reached a low of nearly -$0.05 per gallon. According to Bollen & Whaley (1998), in December of 1993 MGRM had sold 2896.94 million gallons of unleaded gasoline fixed-price contracts. Using this information from and the minimum basis of -$0.05 per gallon, MGRM would have an approximate roll-loss of $145 million using a one-for-one hedge in that month alone.

December 1991 - November 2001

During the 10-year sample period, the bases for heating oil and unleaded gasoline were in some degree of contango for the majority of months: heating oil: 74%, unleaded gasoline: 85%. This is reflected in the mean and median for both heating oil and gasoline over this period which are negative and close to zero (Table 1). The prevalence of contango for this period is counter to MGRM's assumption that petroleum markets are backwardated in the majority of cases. For heating oil, there are far more outliers that are greater than zero, while for unleaded gasoline the majority of outliers are less than zero (Fig. 7). This indicates that in the extreme cases MGRM would experience positive roll-returns for heating oil and negative roll-returns on unleaded gasoline. The maximum outlier for heating oil is $0.33 which is nearly triple the magnitude of the minimum outlier for unleaded gasoline at -$0.13.

The sample period used to calculate MGRM's returns and losses represents what would have happened had MGRM's strategy been left in place. From the information above, it can be seen that on average MGRM would have experienced negative roll-returns, so it is apparent these data do not provide support for MGRM's apriori assumption about the natural state of petroleum markets. It could even be said that carrying-charge hedging / synthetic storage over this period would be a mistake due to the prevalence of contango, and that the expected returns / losses for MGRM's strategy would provide more support for a strategy of risk-avoidance or variance minimization by using a hedge ratio of less than 1.

Results

The monthly losses for hedge ratios 0 - 1.0 are calculated for both heating oil and unleaded gasoline using each loss functions. Examples of the effect of the choice of loss function for a hedge ratio of 1 are shown in figs. 8 - 13. As discussed, losses generated from the squared error and absolute error functions penalize both positive and negative errors to the same degree, as can be seen in the plotted losses in figs. 8 - 11. Losses calculated using the lin-lin loss function only substantially penalize errors that are positive (negative return) as demonstrated in figs. 12 and 13. Tables 2 - 7 show descriptive statistics for heating oil and unleaded gasoline losses generated by each of the different loss functions. Regardless of the loss function chosen, the expected loss for a hedge ratio of 1 is less than or equal to that of any other hedge ratio for both heating oil and unleaded gasoline. In most cases the maximum loss over the sample period is lowest for a hedge ratio of 1. The exceptions are both unleaded gasoline losses calculated using squared error and absolute error.

I use the hedge ratio of 1 as the benchmark and specify the alternative models as hedge ratios ranging from 0.0 - 0.95 in increments of 0.05. The results from the SPA test are shown in table 8. Regardless of the loss function used to generate the losses I would fail to reject the null hypothesis that any of the alternative models outperform the benchmark hedge ratio of 1. These results provide evidence that MGRM's one-for-one hedging strategy would not have been outperformed by a lower, variance-minimizing hedge ratio. Further, these results suggest that had MGRM been allowed to continue their derivatives backed strategy it would not have done any worse by hedging one-for-one than it would have using a minimum variance hedge ratio motivated by a risk avoidance strategy.

Appendix 1: Tables

Table 1: Descriptive Statistics for Basis Relationships

	Mean	StdDev	Minimum	25%	50%	75%	Max
Heating (Prior)	0.006	0.0240	-0.0170	-0.0080	-0.0020	0.016	0.112
Unleaded (Prior)	0.010	0.0190	-0.0170	-0.0030	0.0060	0.017	0.069
Heating (During)	-0.005	0.0060	-0.0220	-0.0090	-0.0050	-0.001	0.005
Unleaded (During)	-0.006	0.0120	-0.0470	-0.0110	-0.0070	-0.003	0.014
Heating (Sample)	0.002	0.0334	-0.0050	-0.0050	-0.0020	0.001	0.330
Unleaded (Sample)	-0.024	0.0317	-0.0365	-0.0365	-0.0185	-0.006	0.066

Table 2: Squared-Error Losses: Heating

Hedge Ratio	Mean	StdDev	Minimum	25%	50%	75%	Max
0.00	0.013	0.044	0	0.001	0.004	0.009	0.393
0.05	0.012	0.042	0	0.001	0.003	0.008	0.373
0.10	0.011	0.040	0	0.001	0.003	0.007	0.354
0.15	0.010	0.038	0	0.000	0.003	0.007	0.335
0.20	0.010	0.036	0	0.000	0.002	0.006	0.317
0.25	0.009	0.034	0	0.000	0.002	0.005	0.299
0.30	0.008	0.032	0	0.000	0.002	0.005	0.282
0.35	0.007	0.030	0	0.000	0.002	0.004	0.265
0.40	0.007	0.028	0	0.000	0.002	0.004	0.249
0.45	0.006	0.026	0	0.000	0.001	0.003	0.234
0.50	0.006	0.025	0	0.000	0.001	0.003	0.218
0.55	0.005	0.023	0	0.000	0.001	0.002	0.204
0.60	0.005	0.022	0	0.000	0.001	0.002	0.190
0.65	0.004	0.020	0	0.000	0.001	0.002	0.176
0.70	0.004	0.019	0	0.000	0.001	0.001	0.163
0.75	0.003	0.018	0	0.000	0.000	0.001	0.150
0.80	0.003	0.016	0	0.000	0.000	0.001	0.138
0.85	0.003	0.015	0	0.000	0.000	0.001	0.127
0.90	0.002	0.014	0	0.000	0.000	0.000	0.116
0.95	0.002	0.013	0	0.000	0.000	0.000	0.105
1.00	0.002	0.012	0	0.000	0.000	0.000	0.095

Table 3: Squared-Error Losses: Unleaded

Hedge Ratio	Mean	StdDev	Minimum	25%	50%	75%	Max
0.00	0.013	0.022	0	0.001	0.005	0.013	0.146
0.05	0.012	0.021	0	0.001	0.004	0.012	0.133
0.10	0.011	0.019	0	0.001	0.004	0.012	0.120
0.15	0.010	0.017	0	0.001	0.004	0.010	0.108
0.20	0.009	0.016	0	0.001	0.003	0.010	0.097
0.25	0.008	0.014	0	0.001	0.003	0.009	0.086
0.30	0.007	0.013	0	0.001	0.003	0.008	0.076
0.35	0.007	0.012	0	0.001	0.003	0.007	0.066
0.40	0.006	0.010	0	0.001	0.002	0.007	0.060
0.45	0.005	0.009	0	0.000	0.002	0.006	0.055
0.50	0.005	0.008	0	0.000	0.002	0.006	0.050
0.55	0.004	0.008	0	0.000	0.002	0.005	0.045
0.60	0.004	0.007	0	0.000	0.001	0.004	0.041
0.65	0.004	0.006	0	0.000	0.001	0.004	0.036
0.70	0.003	0.006	0	0.000	0.001	0.003	0.032
0.75	0.003	0.005	0	0.000	0.001	0.003	0.033
0.80	0.003	0.005	0	0.000	0.001	0.003	0.035
0.85	0.002	0.005	0	0.000	0.001	0.002	0.037
0.90	0.002	0.005	0	0.000	0.001	0.002	0.039
0.95	0.002	0.005	0	0.000	0.000	0.002	0.041
1.00	0.002	0.005	0	0.000	0.000	0.001	0.043

Table 4: Absolute-Error Losses: Heating

Hedge Ratio	Mean	StdDev	Minimum	25%	50%	75%	Max
0.00	0.076	0.085	0.000	0.024	0.060	0.095	0.627
0.05	0.073	0.083	0.000	0.024	0.057	0.090	0.611
0.10	0.070	0.080	0.001	0.024	0.054	0.086	0.595
0.15	0.067	0.077	0.000	0.022	0.052	0.081	0.579
0.20	0.064	0.075	0.001	0.021	0.049	0.077	0.563
0.25	0.061	0.072	0.001	0.021	0.047	0.072	0.547
0.30	0.057	0.070	0.000	0.020	0.045	0.068	0.531
0.35	0.054	0.067	0.001	0.018	0.043	0.064	0.515
0.40	0.051	0.065	0.002	0.016	0.040	0.060	0.499
0.45	0.048	0.062	0.001	0.015	0.037	0.056	0.483
0.50	0.045	0.060	0.000	0.013	0.036	0.052	0.467
0.55	0.042	0.057	0.001	0.013	0.034	0.050	0.451
0.60	0.039	0.055	0.000	0.012	0.029	0.047	0.436
0.65	0.036	0.053	0.000	0.012	0.026	0.042	0.420
0.70	0.033	0.051	0.000	0.010	0.023	0.038	0.404
0.75	0.030	0.049	0.000	0.008	0.019	0.034	0.388
0.80	0.027	0.048	0.000	0.006	0.016	0.030	0.372
0.85	0.024	0.046	0.000	0.005	0.013	0.024	0.356
0.90	0.022	0.044	0.000	0.005	0.011	0.020	0.340
0.95	0.020	0.043	0.000	0.004	0.008	0.019	0.324
1.00	0.019	0.041	0.000	0.003	0.008	0.018	0.308

Table 5: Absolute-Error Losses: Unleaded

Hedge Ratio	Mean	StdDev	Minimum	25%	50%	75%	Max
0.00	0.086	0.072	0.002	0.032	0.070	0.114	0.383
0.05	0.082	0.069	0.003	0.030	0.067	0.110	0.365
0.10	0.079	0.066	0.002	0.028	0.064	0.108	0.347
0.15	0.076	0.064	0.001	0.026	0.062	0.102	0.329
0.20	0.073	0.061	0.000	0.026	0.059	0.098	0.311
0.25	0.069	0.058	0.001	0.026	0.055	0.094	0.293
0.30	0.066	0.056	0.000	0.025	0.051	0.088	0.275
0.35	0.063	0.053	0.001	0.025	0.050	0.083	0.258
0.40	0.060	0.050	0.000	0.023	0.048	0.081	0.245
0.45	0.057	0.048	0.001	0.022	0.045	0.079	0.234
0.50	0.054	0.045	0.000	0.022	0.044	0.076	0.223
0.55	0.051	0.043	0.000	0.021	0.041	0.070	0.212
0.60	0.048	0.041	0.002	0.018	0.039	0.064	0.201
0.65	0.045	0.039	0.000	0.016	0.036	0.060	0.191
0.70	0.043	0.037	0.002	0.015	0.033	0.055	0.180
0.75	0.040	0.035	0.001	0.014	0.029	0.051	0.181
0.80	0.038	0.034	0.000	0.013	0.027	0.051	0.186
0.85	0.035	0.033	0.000	0.013	0.025	0.049	0.191
0.90	0.033	0.033	0.000	0.011	0.023	0.044	0.197
0.95	0.031	0.033	0.000	0.009	0.022	0.041	0.202
1.00	0.029	0.033	0.000	0.006	0.019	0.036	0.207

Table 6: Linear-Linear Error Losses: Heating

Hedge Ratio	Mean	StdDev	Minimum	25%	50%	75%	Max
0.00	0.038	0.076	0	0.001	0.002	0.054	0.620
0.05	0.037	0.073	0	0.001	0.002	0.052	0.605
0.10	0.035	0.071	0	0.001	0.002	0.050	0.589
0.15	0.034	0.068	0	0.001	0.002	0.047	0.573
0.20	0.032	0.066	0	0.001	0.002	0.044	0.557
0.25	0.031	0.063	0	0.001	0.002	0.042	0.542
0.30	0.029	0.061	0	0.000	0.001	0.039	0.526
0.35	0.027	0.058	0	0.000	0.001	0.036	0.510
0.40	0.026	0.056	0	0.000	0.001	0.034	0.494
0.45	0.024	0.053	0	0.000	0.001	0.031	0.478
0.50	0.023	0.051	0	0.000	0.001	0.028	0.463
0.55	0.021	0.048	0	0.000	0.001	0.026	0.447
0.60	0.020	0.046	0	0.000	0.001	0.024	0.431
0.65	0.018	0.044	0	0.000	0.001	0.023	0.415
0.70	0.017	0.042	0	0.000	0.001	0.019	0.400
0.75	0.015	0.040	0	0.000	0.001	0.018	0.384
0.80	0.014	0.038	0	0.000	0.001	0.015	0.368
0.85	0.012	0.036	0	0.000	0.001	0.012	0.352
0.90	0.011	0.034	0	0.000	0.001	0.010	0.337
0.95	0.010	0.033	0	0.000	0.001	0.008	0.321
1.00	0.010	0.031	0	0.000	0.001	0.009	0.305

Table 7: Linear-Linear Error Losses: Unleaded

Hedge Ratio	Mean	StdDev	Minimum	25%	50%	75%	Max
0.00	0.043	0.063	0	0.001	0.004	0.081	0.357
0.05	0.041	0.060	0	0.001	0.004	0.079	0.339
0.10	0.039	0.058	0	0.001	0.003	0.076	0.322
0.15	0.038	0.055	0	0.001	0.003	0.072	0.304
0.20	0.036	0.053	0	0.000	0.003	0.068	0.287
0.25	0.034	0.051	0	0.001	0.003	0.063	0.270
0.30	0.033	0.048	0	0.000	0.002	0.059	0.252
0.35	0.031	0.046	0	0.000	0.002	0.056	0.235
0.40	0.030	0.044	0	0.000	0.002	0.052	0.217
0.45	0.028	0.042	0	0.000	0.002	0.048	0.203
0.50	0.027	0.040	0	0.000	0.002	0.045	0.197
0.55	0.025	0.037	0	0.000	0.002	0.042	0.191
0.60	0.024	0.035	0	0.000	0.002	0.042	0.185
0.65	0.022	0.033	0	0.000	0.003	0.038	0.180
0.70	0.021	0.031	0	0.000	0.004	0.035	0.174
0.75	0.020	0.030	0	0.000	0.003	0.031	0.168
0.80	0.019	0.028	0	0.000	0.004	0.027	0.162
0.85	0.017	0.027	0	0.000	0.002	0.025	0.156
0.90	0.016	0.026	0	0.000	0.002	0.023	0.150
0.95	0.015	0.025	0	0.000	0.002	0.022	0.145
1.00	0.014	0.024	0	0.000	0.002	0.019	0.139

Table 8: Results from SPA Test

Metric	SPA_{lower}	$SPA_{consistent}$	SPA_{upper}
SE (Heating)	0.5471	0.9138	0.9138
AE (Heating)	0.5172	0.5172	0.9943
Lin-Lin (Heating)	0.5151	0.9418	0.9418
SE (Unleaded)	0.4875	0.4875	0.9960
AE (Unleaded)	0.4977	0.4977	1.0000
Lin-Lin (Unleaded)	0.5282	0.5282	0.9974

Appendix 2: Figures

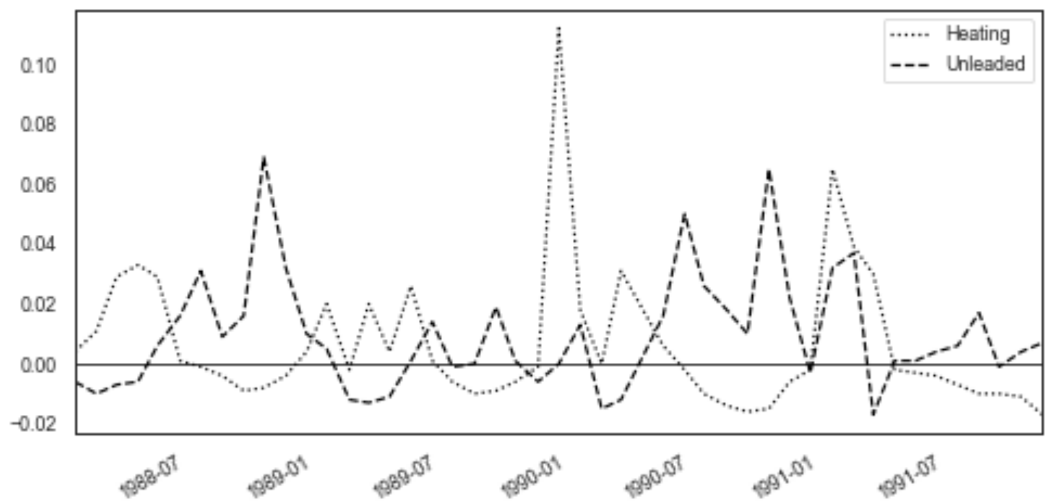

Figure 1: Basis for heating oil and unleaded gasoline 1988 - 1991

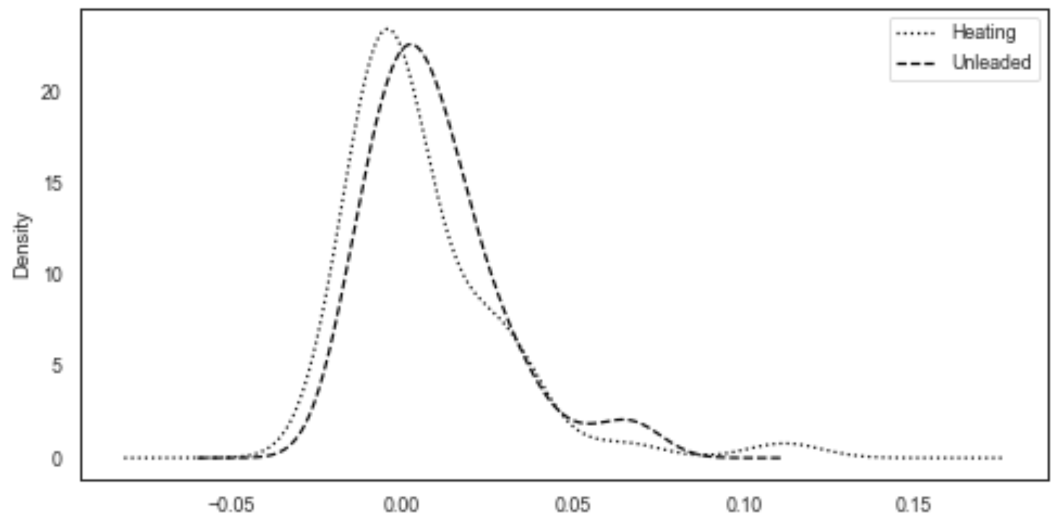

Figure 2: Density plot for heating oil and unleaded gasoline 1988 - 1991

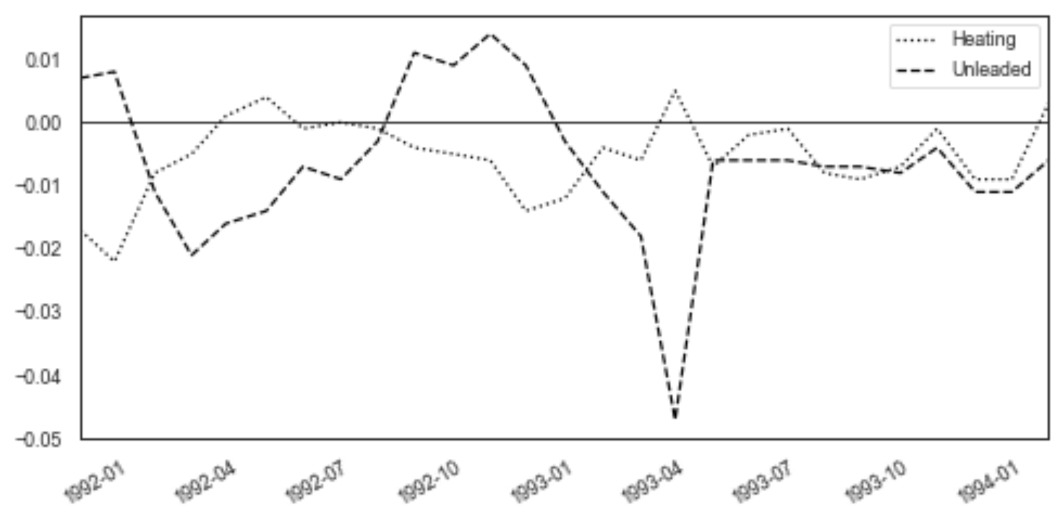

Figure 3: Basis for heating oil and unleaded gasoline 1991 - 1994

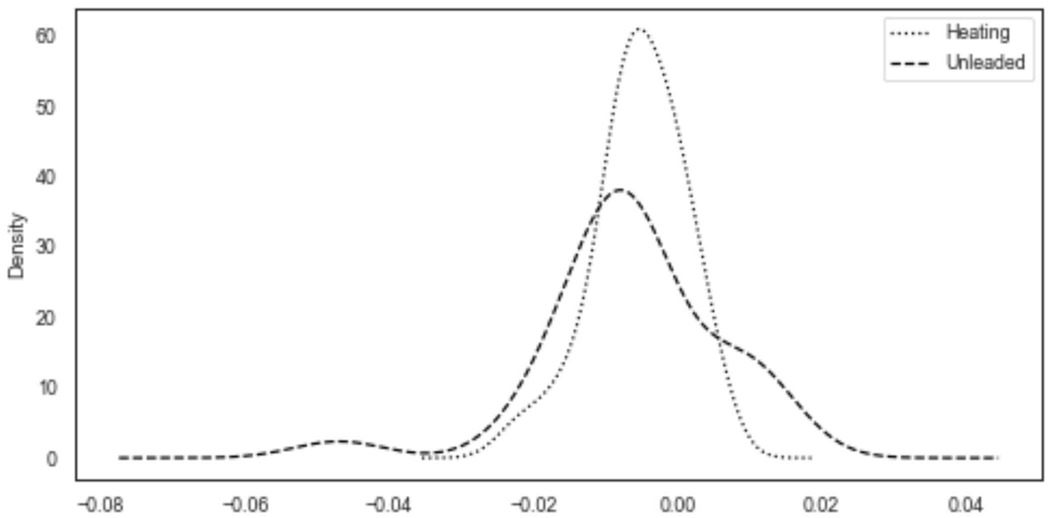

Figure 4: Density plot for heating oil and unleaded gasoline 1991 - 1994

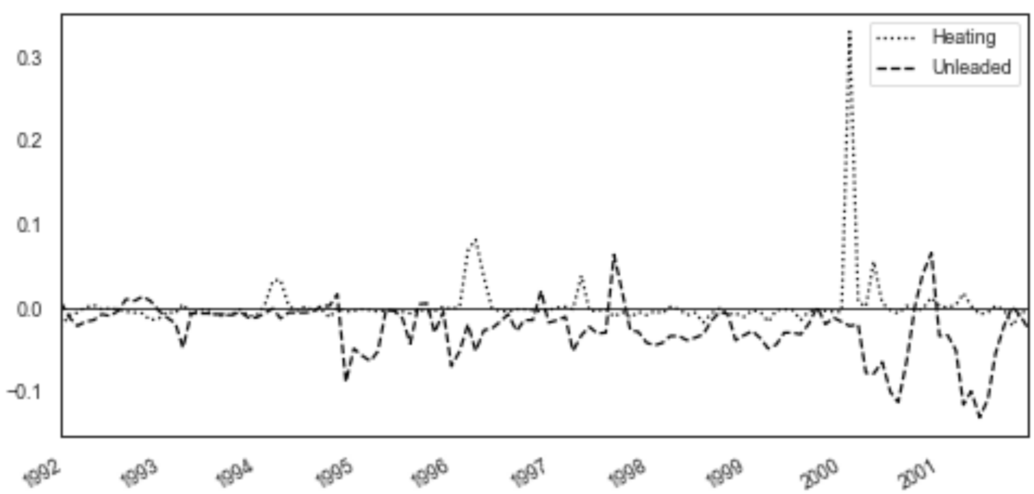

Figure 5: Basis for heating oil and unleaded gasoline 1991 - 2001

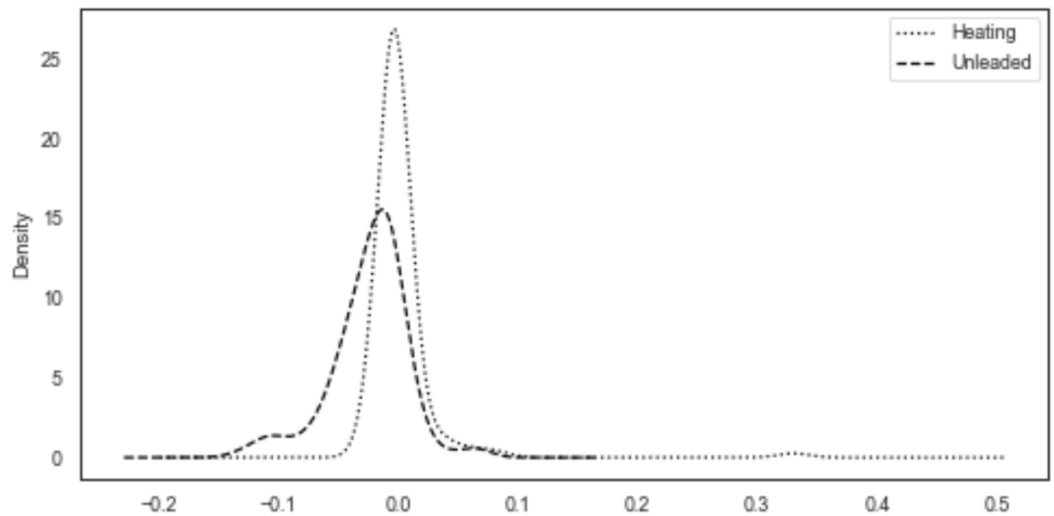

Figure 6: Density plot for heating oil and unleaded gasoline 1991 - 2001

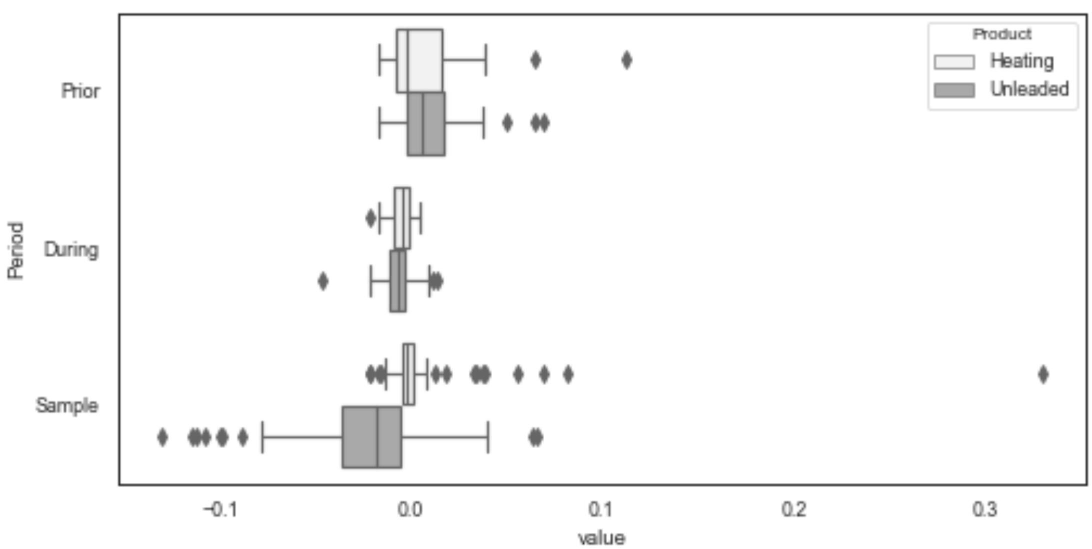

Figure 7: Box Plots of Basis Relationships Prior, During, and over the Sample Periods

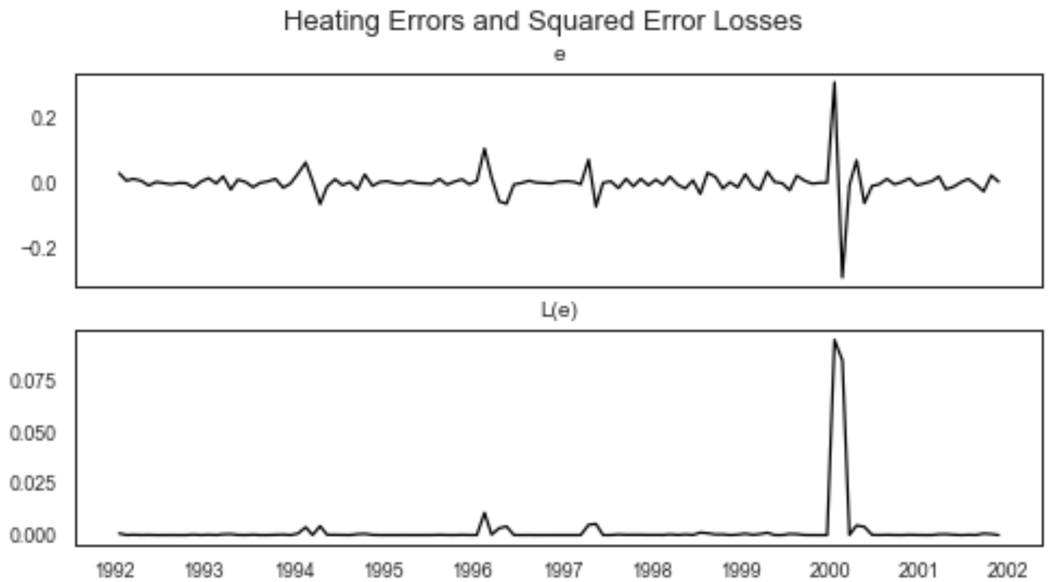

Figure 8: Errors and Squared Error losses for Heating Oil 1991 - 2001

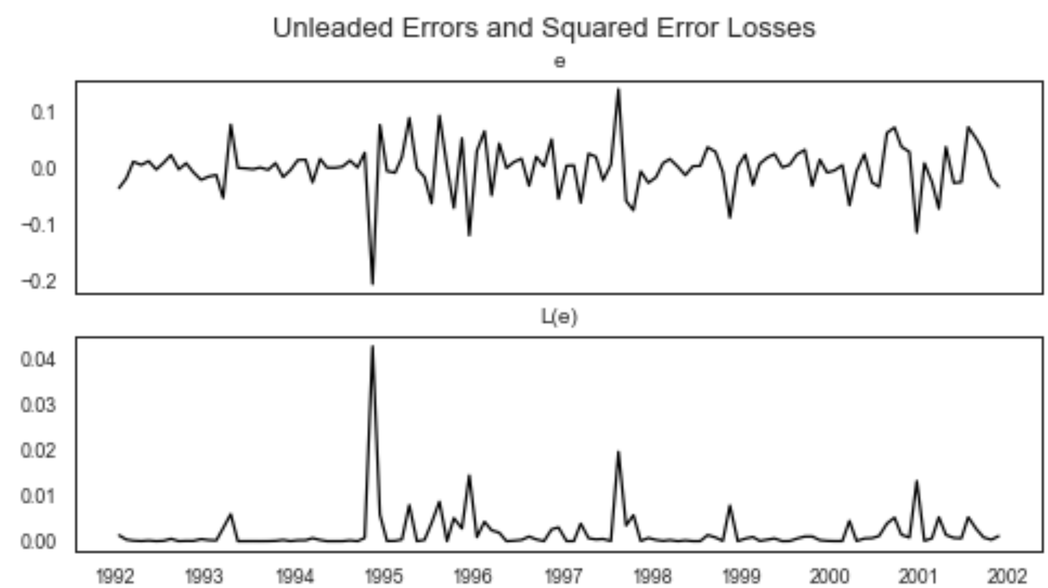

Figure 9: Errors and Squared Error losses for Unleaded Gasoline 1991 - 2001

Figure 10: Errors and Absolute Error losses for Heating Oil 1991 - 2001

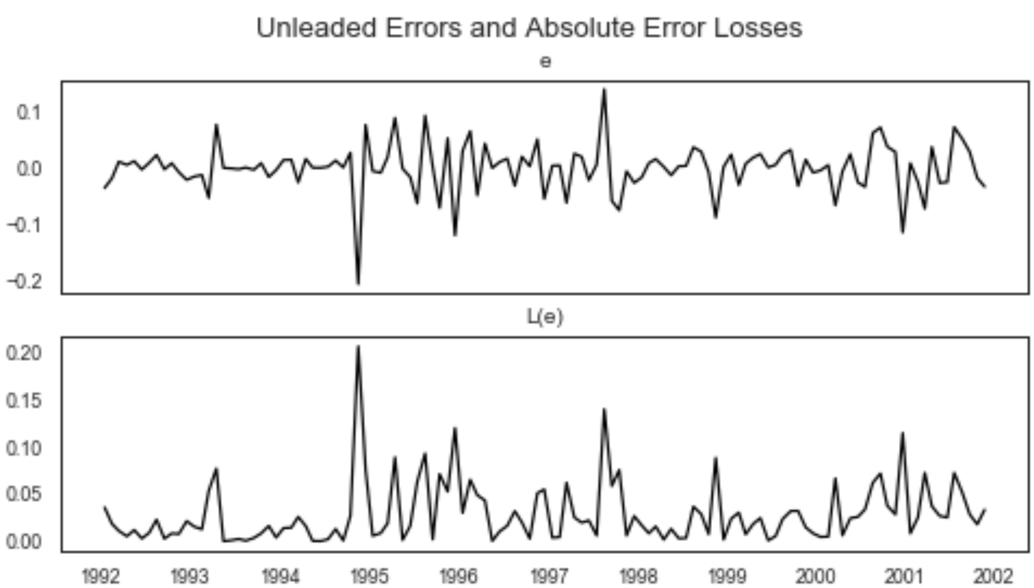

Figure 11: Errors and Absolute Error losses for Unleaded Gasoline 1991 - 2001

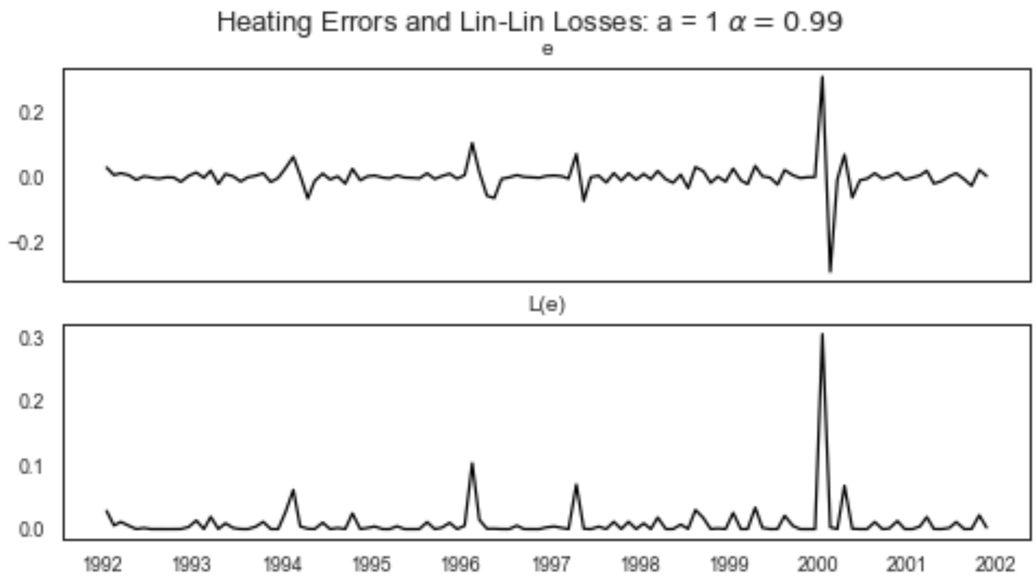

Figure 12: Errors and Lin-Lin Error losses for Heating Oil 1991 - 2001

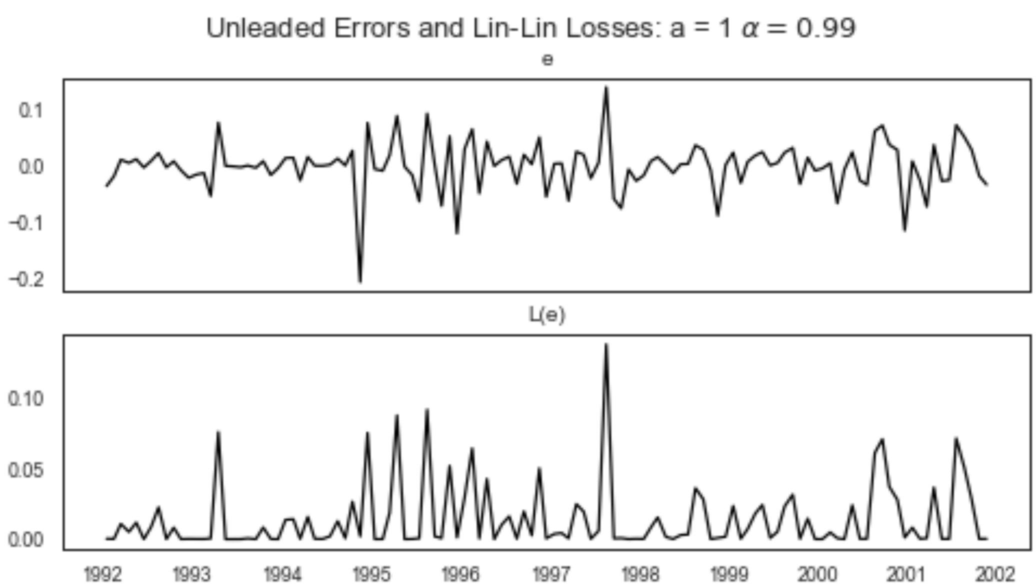

Figure 13: Errors and Lin-Lin Error losses for Unleaded Gasoline 1991 - 2001

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