The Influence of Fuel Price on an Automaker's Decision to Lightweight Cars via Materials Substitution

by

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Abstract

The following study examines how the costs and benefits of improving fuel economy of vehicles via lightweighting with aluminum closures change with gas price. A process-based cost model is used to evaluate the costs of lightweighting with aluminum for six representative vehicles, and an industry choice-based conjoint decision analysis market model is used to evaluate the benefits of lightweighting given a 0.5mpg increase in fuel economy. Vehicles were examined by class size. Compact car owners were observed to be willing to pay for improved fuel economy but consumer preferences indicate insufficient willingness to pay to cover the costs of lightweighting with aluminum for a representative compact car, the Toyota Corolla. However, no conclusion can be made as to whether larger car owners are or are not willing to pay for improved fuel economy.

Acknowledgements

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I. Introduction and Background

Recent increases in the volatility of fuel price [1] have increased the awareness of fuel economy to the average U.S. consumer; 92% of occupied household units in the United States own cars [2] and record oil prices in the summer of 2008 sparked widespread media coverage over the high price of fuel [3]. Understanding and modeling consumer preferences for fuel economy is of increasing importance to automobile companies and can be a key driver in manufacturing and production decisions.

Automobile companies have various options to improve the fuel economy of their vehicles, and the method of lightweighting, that is, vehicle weight reduction, is the focus of the following thesis. Lightweighting vehicles via materials substitution is an option automobile companies have to increase fuel economy of cars, but lightweighting also includes an additional materials cost; for example, aluminum, a common material used to lightweight due to its low density and high stiffness [4], can cost up to four times the cost of steel. Moreover, more expensive aluminum press dies and slower line rates for production further increase the cost of manufacturing aluminum closures. The following study seeks to analyze how fuel price affects consumer preferences for fuel economy and therefore the value to the automaker of improving fuel economy. The study then contrasts this value to the cost of lightweighting vehicles to determine when it is cost beneficial for automobile companies to improve fuel economy.

In order to answer the question of whether companies should use lightweight materials to achieve fuel economy improvements, the cost-benefit trade-off is examined by vehicle size. Cost depends on the market segment of the vehicle as well as the material system used to produce the vehicle. The benefits of lightweighting depend on how much fuel economy improvement lightweighting provides, which depends on the market segment of the vehicle. Furthermore, the benefits of lightweighting depend on how much fuel economy is worth to the consumer, and it is hypothesized here that both market segment and fuel price influence the value of improved fuel economy to the consumer.

To clarify, the following hypotheses are tested in the following study. First, it is hypothesized that people are willing to pay for increased fuel economy. The price of a good is intuitively linked to the characteristics of the product (e.g. hedonic prices), and consumers should be willing to pay for an improvement that would effectively decrease their lifetime fuel consumption. Second, it is hypothesized that fuel price influences a consumer's desire for improved fuel economy. This is believed because consumers save more money with higher fuel economy vehicles when fuel prices are high. Finally, it is hypothesized this willingness to pay for fuel economy and the influence of gas prices on consumer preferences for fuel economy is influenced by the size of the vehicle (market segment).

Prior research on consumer willingness to pay for increased automobile fuel economy is scarce [5]. Studies that do exist utilize hedonic pricing methods or household surveys to determine this relationship [5,6,7] while a discrete choice-based conjoint analysis (CBC) is implemented in this study. CBC predicts consumer preferences based on past consumer behavior and is another method of determining willingness to pay [8]. While CBC analysis has been used for to study consumer preferences of technological changes in automobiles [9] and general market strategies [10], no studies were found to focus on examining the relationship between consumer willingness to pay for increased fuel economy due to lightweighting specifically. Moreover, while Li et al seeks to determine the relationship between fuel price and fuel economy based on automobile company decisions reflected in automotive fleet compositions [11], this study looks to determine if a relationship exists between fuel price and consumer preferences for fuel economy. Finally, Popp et al determined high-income Americans are not concerned about fuel economy [12], but this study looks to examine consumer fuel economy preferences and willingness to pay for fuel economy by vehicle size instead.

In short, the hypotheses stated above are tested by using an industry CBC model to extrapolate changes in market share for fuel economy and price over the last two years. The consumer willingness to pay for improved fuel economy is determined using these extrapolated values, and the statistical significance of regressions between consumer willingness to pay over time and gas price over time is analyzed. The consumer willingness to pay is compared to the cost to automobile manufacturers of lightweighting with aluminum closures projected by process-based cost modeling, and the gas price at which it becomes cost-beneficial for automobile companies to improve fuel economy using this specific method is determined.

II. Methods

As noted above, the purpose of this thesis is to determine whether fuel price can potentially influence an automaker's decision to lightweight cars via materials substitution. This analysis requires cost models to determine the cost of lightweighting cars to the automaker, a means to translate weight savings due to lightweighting into fuel economy improvement, a market model to ascertain a consumer's willingness to pay for improved fuel economy, and a statistical analysis to determine if a relationship exists between this consumer's willingness to pay and fuel price. The cost to the automaker of improving fuel economy and the consumer's willingness to pay as derived from the statistical analysis are then compared to determine the fuel prices under which lightweighting is favorable. This process is repeated for a car in each of the market segments considered in this study. A method to scale (by material and size) a baseline vehicle is also needed for cost analysis because we only have the vehicle design for mild steel closures for midsize cars [13].

The mild steel closure set design for a midsize car was first converted into an equivalent Al closure set for a midsize car assuming constant panel stiffness (following the method described in [13]). The midsize Al closure set was then scaled to compact and large vehicle sizes by scaling the lengths and widths of each component by relative sizes of the car. The adjusted part dimensions and resulting mass of the closure part served as inputs in the cost models. The cost of forming and assembling aluminum closures was compared to the cost of forming and assembling mild steel closures for varying class sizes and production volumes, and the cost premium, or the extra cost due to aluminum lightweighting of closures, determined. Details of scaling midsize closures to compact closures are provided in *Appendix A*, and scaling to large closures is analogous to scaling to compact closures.

Cost modeling is carried out using process-based cost models (PBCMs) developed by the Materials Systems Lab [14]. Process-based cost models predict the cost of manufacturing a part by breaking down the costs associated with each manufacturing step. Because they take a bottom-up approach to cost estimation, they are useful in predicting the costs of emerging processes. Stamping and extrusion PBCMs are used to evaluate the forming cost of car closures (See *Figure 1*) in this study, and an assembly cost model to estimate the cost of joining the individual parts. More details regarding the PBCMs used can be found in the aforementioned publication. *Table 1* lists examples of exogenous model inputs. Material prices are averages for the industry and representative of what a manufacturer might pay. *Table 2* gives an example of a closure part input.

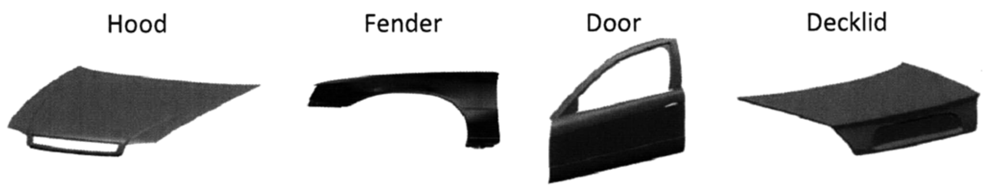

Figure 1: Typical Vehicle Closures

To determine the benefits of lightweighting, the closure weight savings from the steel-aluminum conversion was calculated for each size car and translated into savings in fuel economy. Fuel economy improvement for passenger vehicles is sometimes approximated to increase 6-7% per 10% weight reduction [15,16], while other researchers in the field conclude "no general value for the fuel consumption reduction per weight reduction exists" [17]. A low-end approximation of a 5% increase in fuel economy per 10% weight reduction of the car is used in these calculations, and it is noted here that the actual value of fuel economy improvement may be different.

In order to determine whether a relationship exists between consumer willingness to pay for fuel economy improvement and gas price at the pump, we used a proprietary industry market model to analyze consumer preferences over time. The market model predicts the change in automobile market share as a function of various vehicle attributes based on data gathered from online sessions with potential consumers. Data for specific vehicles was obtained weekly over a two-year span and limited to the U.S. market. The minimum potential consumer session duration was set at the default time of three minutes. The relationship between the change in market share, *dMS,* and 1) change in fuel economy, *dFE,* and 2) change in vehicle price, *dP,* was determined for each chosen vehicle given a range of fuel economy improvements and increases in vehicle price. The initial market share of each vehicle was also established. The price at which the change in market share is zero for a given change in fuel economy (due, in this study, to aluminum lightweighting) was estimated and this price, known also as the volume-neutral price (*VNP*), is reflective of consumer value or willingness to pay (*WTP)*. More explicitly, VNP was calculated as described below:

Assuming fuel economy and price affect market share independently and that change market share varies linearly with changes in these two attributes,

$$m_{FE} = \frac{dMS}{dFE}, \; m_P = \frac{dMS}{dP}$$
$$\Delta MS = m_{FE}\Delta FE + m_P \Delta P$$

where m_{FE} is the change in market share for a vehicle given a change in fuel economy, and m_p is the change in market share for a vehicle given a change in price. If ΔMS = 0 for some given improvement in fuel economy (i.e. ΔFE), then

$$\Delta P(\Delta MS = 0) = VNP - P_o \equiv WTP$$

where P_o is the initial price of the unimproved vehicle and

$$\Delta MS = 0 = m_{FE}\Delta FE + m_P WTP$$
$$WTP = -\frac{m_{FE}}{m_P}\Delta FE$$

The sensitivity of consumer willingness to pay to fuel price over time was examined using Microsoft Excel, a spreadsheet application program with calculation and graphing tools, and StataCorp's Stata, a statistical software package with regression analysis capabilities. Regressions were run to tease out a linear relationship between the independent (gas price over time) and dependent (WTP over time, market share over time, etc.) variables. For some regressions, and eight-week moving average was used to smooth out the WTP data. Moreover, consumer sensitivity to the average gas price over the last couple of months (versus weekly gas prices) was examined by using four and eight-week moving averages of gas price in some regressions. T-statistics were calculated to determine if the regression relationships were statistically significant, and Durbin-Watson statistics were determined to check the autocorrelation of the time-series data. If the data was found to be autocorrelated, Cochran-Orcutt Prais-Winsten analysis was run to generate a corrected Durbin-Watson statistic. A summary of statistical tests is provided in *Table 3*. Determining which relationships were statistically significant enabled refinement of the above-stated thesis question and comparison of the cost of improving fuel economy with a given consumer willingness to pay. Finally, this willingness to pay was compared with the cost to lightweight aluminum closures calculated by the cost models for different vehicle sizes.

III. Case Description

Using the methodology described above, the cost of improving fuel economy was evaluated by finding the cost premium to lightweight car closures with aluminum. Closures are easily exchanged, and focusing on these parts enables the result to be generalized to various car models. All inner and outer panels and reinforcements were included the cost modeling, and the forming and assembly costs of the closures were modeled. A complete list of closure parts modeled with the cost models used is listed in *Appendix B*.

Table 1: Example Cost Model Inputs

Exogenous Variable	
Days worked per year	235 days/yr
Labor wage	US $35.00/hr
Energy cost	US $0.07 kW/hr
Building unit cost	US $2,000 / sq m
Interest rate	15%
Product life	5 yrs
Equipment life	13 yrs
Building life	40 yrs
Material Prices	
Mild Steel sheet	US $1.26/kg
Al 6111-T4 sheet	US $4.97/kg
Al 6111 (inner) sheet	US $4.83/kg
Al 6061 billet	US $2.98/kg

Table 2: Example Part Input: Aluminum Midsize Car, Inner Hood Panel

Material	Al 6111 (inner)
Complexity (1,2,3)	3
Finishing (0-No, 1-Yes)	0
Press Type	Tandem
Part Information	
Weight (kg)	3.38
Width (mm)	1204.57
Length (mm)	1539.68
Final Surface Area (sqm)	2.41
Projected Surface Area (sqm)	1.85
Blank (or Coil) Information	
Preblank cost (USD)	$0.00
Gage (mm)	1.1
Width (mm)	1732
Length (mm)	1318

Table 3: Summary of Statistical Tests

Statistical Test	Purpose	Interpretation of Results
T-statistic, *t*	Measures the statistical significance of the relationship between an independent and dependent variable in a regression analysis.	If ***t*** is ≥ 2, the relationship observed is statistically significant.
Durbin-Watson statistic, *d*	Detects autocorrelation in the residuals of a regression analysis.	If ***d*** is < 2, successive terms are positively correlated. If ***d*** is > 2, successive terms are negatively correlated. If ***d*** = 2, no autocorrelation exists.
Prais-Winsten (Cochran-Orcutt)	Adjusts the linear model for autocorrelation in the error term and outputs a revised ***t*** and ***d.***	See above.

Scaling closures from a steel baseline to an aluminum design was carried out following a method T. Montalbo used in [13]. The manufacturing of aluminum sheet closures is similar to that of steel closures except different material costs and processes are used. Compact and large vehicle closure sizes were scaled from baseline closures of a representative midsize vehicle. Scaling ratios were determined from average vehicle sizes listed in *Table 4*. Average vehicle sizes were extrapolated by averaging, for each class size, three representative 2007 models. Representative models were chosen by largest market share and 2007 data was the most recent data available. The Chevrolet Cobalt, Honda Civic, and Toyota Corolla were chosen for the compact class size, the Honda Accord, Nissan Altima, and Toyota Camry for the midsize class size, and the Chrysler 300 Series, Chevrolet Impala, and Hyundai Sonata for the large class size. As noted before, details of scaling midsize closures to compact closures are provided in

Appendix A, and scaling to large closures is analogous to scaling to compact closures. The resulting values were inputs in the respective cost models (stamping, extrusion, or assembly; see *Appendix B*). A combination of spot welding and die hemming was used for joining mild steel closures while spot welding and roller hemming were used for joining aluminum closures. 20% more spot welds were used for joining aluminum closures.

Costs of closures were evaluated as a function of annual production volume (20K, 60K, 200K) and vehicle size (compact, midsize, large) and the cost premium of replacing steel closures with aluminum closures over a range of production volumes was observed.

Two cars of each U.S. Environmental Protection Agency (EPA) class size (compact, midsize, and large) were chosen for the consumer value analysis: the Chevrolet Aveo and Toyota Corolla were the compact choices, the Chevrolet Malibu and Toyota Camry the midsize choices, and the Chevrolet Impala and Toyota Avalon the large choices. All models were the latest models (2009).

Table 4: Average Vehicle Sizes

	Wheelbase (in)	Width (in)	Curb Weight (kg)	Height (in)
Compact Coupe	103.67	67.92	1224	56.57
Midsize Coupe	108.12	71.26	1472	57.21
Large Coupe	112.63	73.93	1698	57.67

Using the industry market model, the change in market share for each car was observed weekly from Monday December 25, 2006, 12AM PST to Monday January 5, 2009, 12AM PST for a given change in fuel economy or a given change in price. The weekly time period was chosen to correspond to available gas price data. Comparable market model data is not available prior to December 2006. A range of 0.2-1.0 mpg increases in increments of 0.2 mpg in fuel economy were chosen to reflect a 1-2% increase in fuel economy for cars. $50-$250 increases in increments of $50 in price were chosen to reflect typical increases in vehicle price due to changes in materials substitution. Changes to fuel economy or price were applied to all trims for each model for each run. *Appendix C* summarizes the details of each run.

The changes in market share (dMS) per unit change in fuel economy (dFE) or price (dP) were extracted using the *slope(y, x)* function in Microsoft Excel. The changes in market share for each car were the sums of the changes in market share for all trims of each model for a particular week. These slopes (m_{FE}, m_P) were compiled for each week and each car, and consumer willingness to pay (WTP) for a reasonable increase in fuel economy due to lightweighting was calculated.

Weekly baseline market shares were also extracted from the market model data and summed across all trims for each car. These were used to normalize the change in market share for analysis purposes.

The statistical analysis was primarily carried out using Stata and was used to determine if a relationship exists between WTP and fuel price. The analysis was carried out with weekly U.S. retail gasoline price (all grades, all formulations) data from the EIA [18], and the absolute and change in gas price for time-lagged and non-time-lagged gas series was regressed with WTP and MS for each car over time. Moving averages of WTP, MS, and gas price were also considered in the analysis. A full list of statistical tests carried out is listed in *Appendix D.*

IV. Results

A. Aluminum Closure Scaling & Cost Model Inputs

Scaling results for aluminum closures are listed in *Appendix E. Table 5* displays the cost of aluminum closures at 20k, 60k, and 200k annual production volumes for compact, midsize, and large vehicles. *Figure 2* displays a breakdown of forming and assembly costs for the midsize vehicle at different production levels. Cost breakdowns for compact and large cars are similar to those displayed in *Figure 2* and can be found in *Appendix F*. *Figure 3* displays the cost of forming and assembling mild steel and aluminum closures as a function of production volume for midsize vehicles (similar graphs for compact and large vehicles can be found in *Appendix G*), and the cost premium, or the extra amount automobile companies are projected to pay by forming and assembling aluminum closures instead of mild steel closures is graphed as a function of production volume for compact, midsize, and large cars in *Figure 4*. As expected, aluminum closures cost more than steel closures and the cost premium of using aluminum in large cars is higher than the cost premium in smaller cars (for some given volume). This is expected because the aluminum closures are formed from stamped aluminum sheets and are thus expected to respond to economies of scale the same way steel closures do. That is, there is a higher cost premium at lower volumes.

Table 5: Forming and Assembly Costs (in USD) of Aluminum Closures

	Annual Production Volume		
Vehicle Size	**20,000**	**60,000**	**200,000**
Compact	$824.24	$480.34	$374.66
Midsize	$863.86	$517.28	$409.72
Large	$896.56	$545.75	$438.85

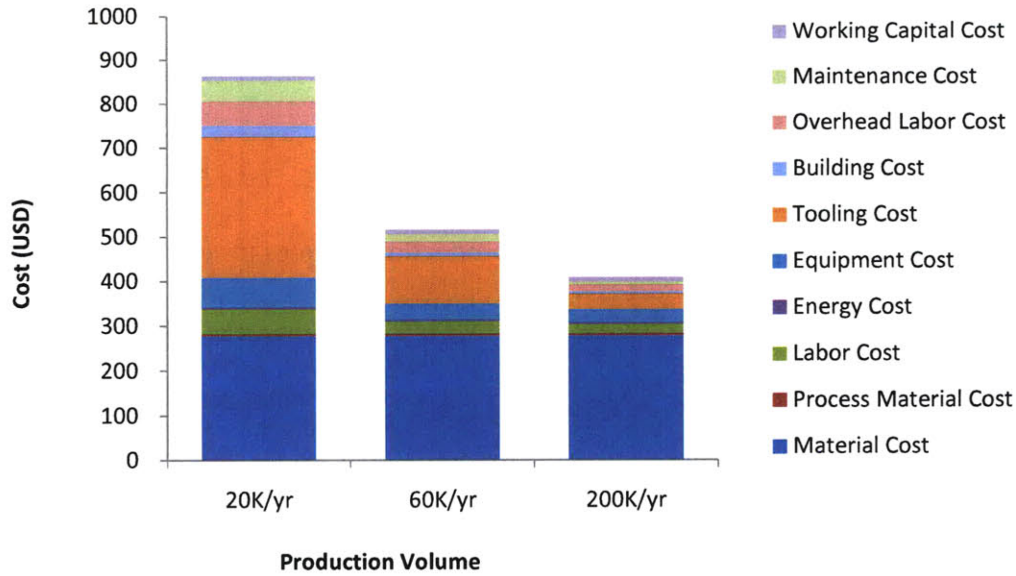

Figure 2: Breakdown of Costs for Midsize Aluminum Closures– Costs include forming and assembly costs.

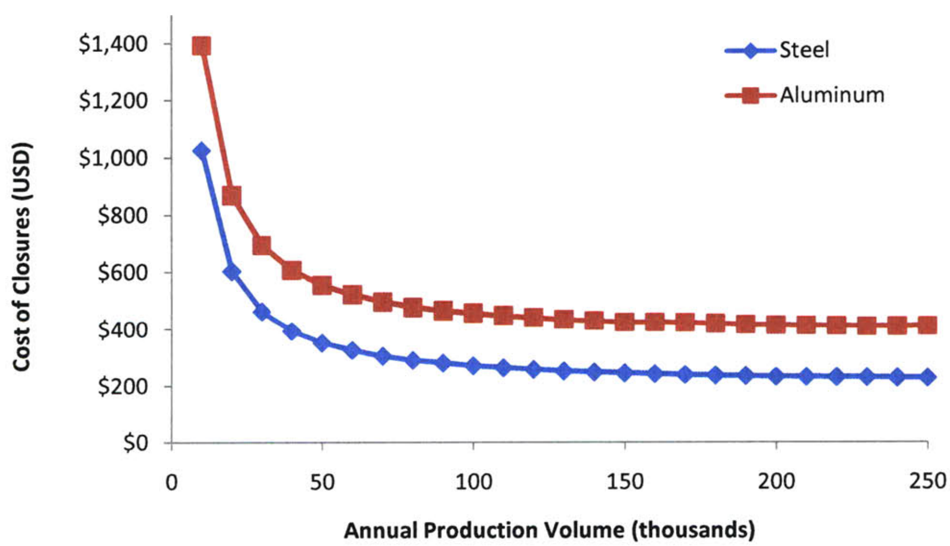

Figure 3: Cost of Midsize Steel and Aluminum Closures

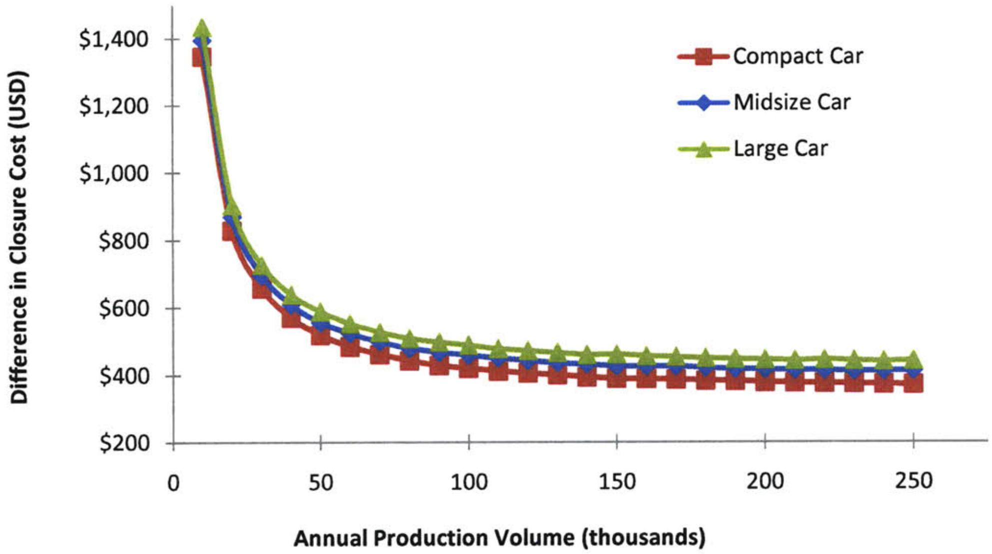

Figure 4: Cost Premium of Substituting Mild Steel Closures with Aluminum

B. Fuel Economy Improvements from Weight Savings

A decrease of 2% in weight was observed with the lightweighting of vehicle closures by aluminum. Using the approximation stated above that a 10% reduction in weight results in a 5% increase in fuel economy, the increase in fuel economy is approximated to be +1-2% for vehicles of all sizes examined in this study. Given the average fuel economy of the cars examined in this study for each class size, the absolute increase in fuel economy is calculated to range from 0.3-0.6mpg (see *Table 6*). A fuel economy increase of +0.5mpg, which is near the upper limit of fuel economy improvement estimated for midsize and large vehicles, was used for the following willingness to pay calculations.

Table 6: Weight Reduction of Vehicle Closures

	Weight Reduction (%)	+FE (%)	Average Vehicle FE (mpg)	+FE (mpg)
Compact	2.01	1-2	28.8	0.3 – 0.6
Midsize	1.99	1-2	25.2	0.3 – 0.5
Large	2.01	1-2	23.0	0.3 – 0.5

C. Willingness to Pay (or Volume-Neutral-Price) and Gas Price

Volume-neutral-price (VNP) was calculated (detailed in the *Methods* section) from industry market model data assuming the aforementioned 0.5mpg increase in fuel economy. *Figure 5* displays an 8-week moving average of the volume-neutral-price (a measure of the consumer's willingness to pay) for a 0.5mpg increase in fuel economy during 2007 and 2008. Absolute gas price over time is graphed on the secondary y-axis. Volume-neutral-price is also graphed over time with absolute change in gas price on the secondary axis in *Figure 6*. Moreover, change in market share for all vehicles is displayed in *Figure 7* and market share as a fraction of the overall market for all vehicles is shown in *Figure 8*. Finally, a detailed list of statistical results can be found in Appendix H.

V. Discussion

A. Costs of Aluminum Lightweighting

As noted in *Table 5,* the cost of Al closures decreases with increasing production volume and increases for larger vehicle sizes. This is as expected since cost per unit decreases with higher volume productions and that larger vehicles require more material and thus cost more. The decreasing logarithmic-like (around the order of $x^{-0.3}$) pattern observed is also expected; at

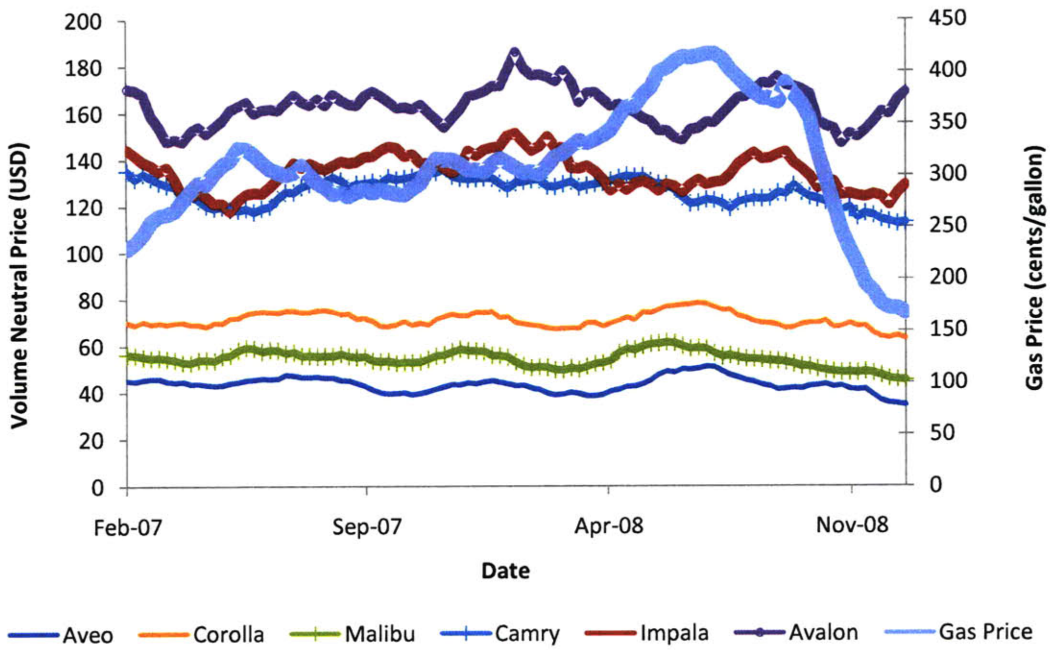

Figure 5: VNP of All Vehicles – VNP is an eight-week moving average for all cars. Absolute gas price is on the secondary y-axis.

some point the rate of decrease of cost per unit due to increased production volume slows down and levels out since a large portion of manufacturing costs for automobiles are fixed.

Figure 2 indicates that the majority of the cost of forming and assembling midsize aluminum sheet closures is due to material costs for higher annual production volumes (60K, 200K). At low volumes (20K/year), the majority of the costs are due to tooling costs, but it is noted that tooling costs, along with equipment costs and other fixed costs, decline at high volumes. Similar results are observed in the cost breakdown charts for compact and large vehicle closures.

Figure 3 shows that the costs of mild steel and aluminum closures follow similar trends with increasing production volume; as production volume increases, the cost of forming and

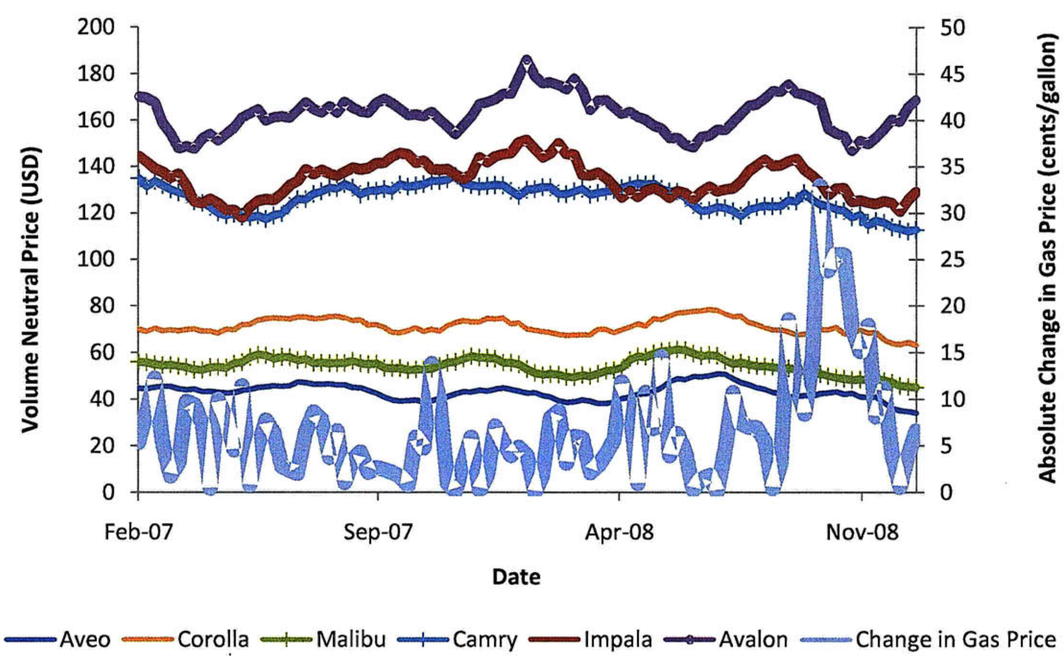

Figure 6: VNP of All Vehicles with Change in Gas Price – VNP is an eight-week moving average for all cars. Absolute change in gas price is on the secondary y-axis.

assembling the closures initially drops steeply and then eventually levels out. This trend is as expected because both aluminum sheets and mild steel sheets are predominately formed by stamping. Also, the cost to form aluminum sheet closures is expected to be higher than the cost to form mild steel closures because of the slightly higher tool investments and material prices associated with aluminum closure production.

Finally, *Figure 4* shows that the cost premium of substituting mild steel closures with aluminum closures increases with larger cars. This trend is as expected since larger cars require larger closures.

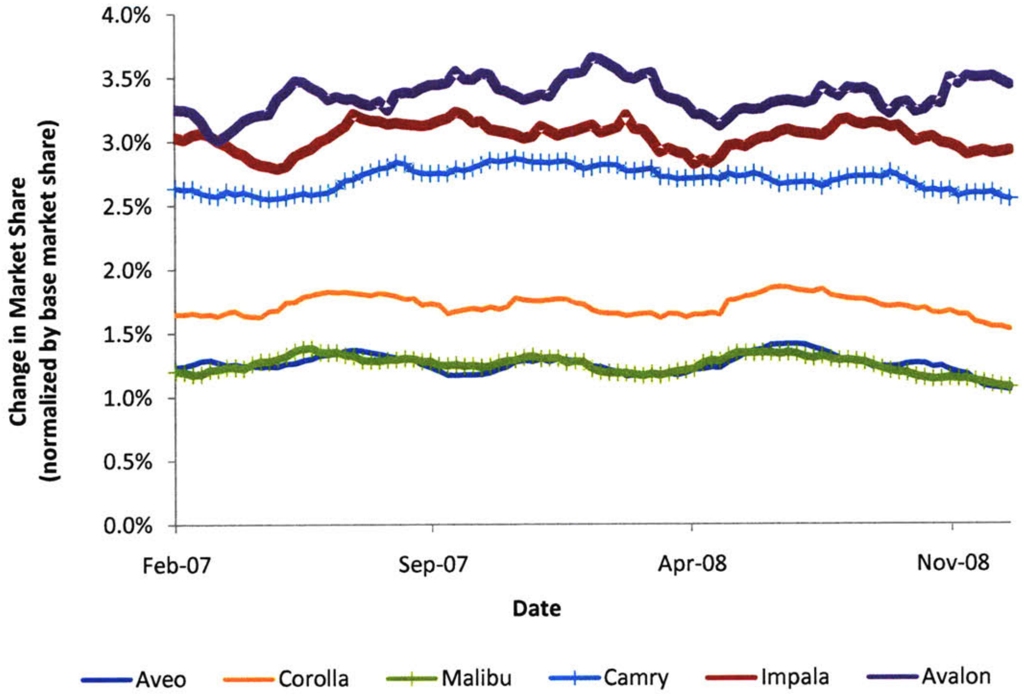

Figure 7: Change in Market Share – The change in market share given a +0.5mpg increase in fuel economy is observed to be positive for all six cars.

B. Willingness to Pay (WTP)

Figure 5 and the regression statistics listed below in *Table 7* indicate that a statistically significant linear relationship exists between the gas price and the VNPs of the 2009 Aveo, Malibu, and Corolla, while the relationships observed between gas price and the VNPs of the rest of the cars are not statistically significant. Interestingly, the Aveo, Corolla, and Malibu are the three smallest cars in the vehicle set observed; the EPA classifies Aveo and Corolla as compact vehicles and the Malibu as a midsize vehicle. The Camry, while also classified as midsize, does not display a statistically significant relationship between VNP and gas price. Thus, it can be concluded from this data that willingness to pay is correlated with fuel price for consumers who prefer small cars; exact regression coefficients (alpha) are provided

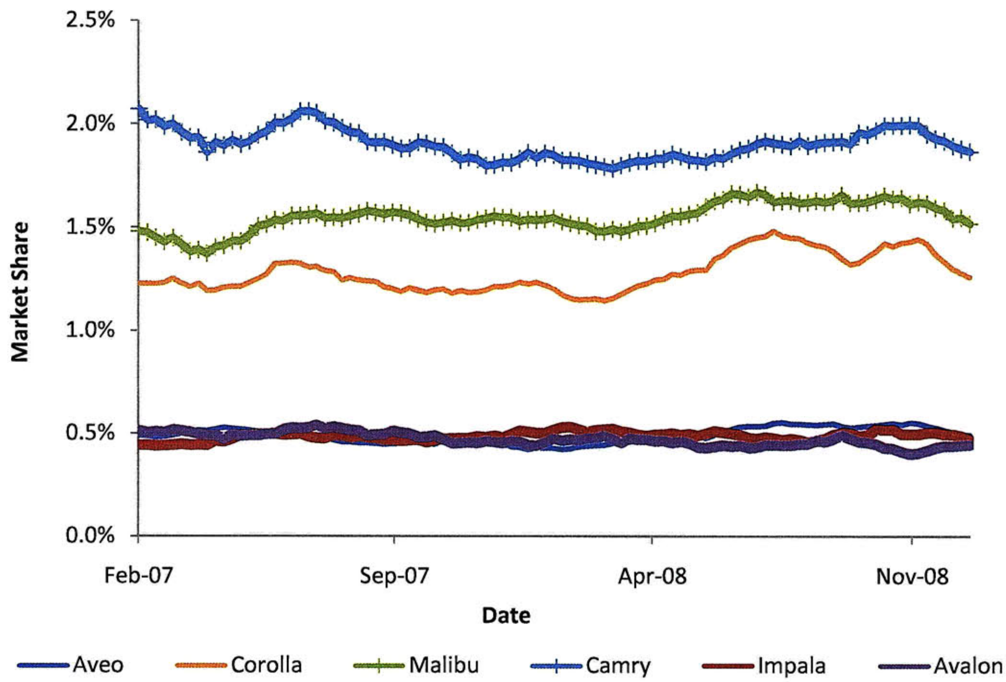

Figure 8: Market share of Vehicles – The market share of the un-lightweighted vehicles is graphed over time.

in *Table 7*. However, a relationship between WTP and fuel price for consumers who prefer midsize cars is unclear, while the relationship for consumers who prefer large cars cannot be statistically verified.

In order to determine why no statistical relationship was found between a consumer's willingness to pay and fuel price for consumers who prefer larger vehicles, the following alternate hypotheses were examined. First, it was hypothesized that consumers who prefer large vehicles may care more about the *absolute change* in fuel price rather than the absolute value of fuel price since consumers who prefer larger vehicles may be more wealthy and not care about the absolute price as much as consumers who prefer small vehicles. Second, it was hypothesized that consumers who prefer larger vehicles do not care about fuel economy to begin with since they prefer vehicles with lower fuel economies to begin with. Finally, it was hypothesized that instead of being willing to pay for changes in gas price, consumers switched class size preferences to account for changes in gas price. For instance, as gas price increases, consumers previously thinking of buying an Impala may decide to switch class size and buy a smaller Malibu or an Aveo instead; their willingness to pay for improved fuel economy is thus not counted for the larger car.

Table 7: Relevant Results of Statistical Tests – T and Durbin-Watson (DW) statistics that are significant are *italicized*.

Regression* (y, x)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)
VNP, Gas Price						
Aveo	0.0366	*4.56*	1.26	0.0391	*3.42*	*2.12*
Malibu	0.0339	*3.72*	1.28	0.0385	*3.00*	*2.09*
Impala	(0.0013)	(0.05)	*1.82*	0.0020	0.07	*2.01*
Corolla	0.0383	*3.61*	*2.07*	0.0430	*4.35*	*1.97*
Camry	0.0121	0.70	1.36	0.0236	1.09	*2.03*
Avalon	(0.0173)	(0.51)	*1.91*	(0.0147)	(0.42)	*1.99*
VNP, Change in Gas Price						
Aveo	(0.0440)	(0.49)	1.05	(0.0619)	(0.61)	*2.16*
Malibu	(0.2277)	*(2.36)*	1.20	(0.1844)	(1.66)	*2.10*
Impala	(0.4244)	(1.57)	*1.89*	(0.3876)	(1.39)	*1.97*
Corolla	(0.0148)	(0.13)	*1.86*	(0.0003)	(0.00)	*2.00*
Camry	(0.3822)	*(2.23)*	1.43	(0.3038)	(1.62)	*2.00*
Avalon	(0.6272)	(1.84)	*1.97*	(0.6337)	(1.84)	*1.96*

However, *Figure 6* and the regression statistics listed above disprove the first hypothesis. The relationships between willingness to pay and the change in fuel price were not found to be statistically significant for consumers who preferred vehicles of any of the three class sizes examined in this study. Moreover, *Figure 7* disproves the second hypothesis; given a 0.5mpg increase in fuel economy, the change in market share for all vehicle class sizes is positive. This indicates that the consumers in this study were not indifferent to improved fuel economy. In fact, they appear to like improved fuel economy regardless of vehicle class size preference and those who prefer large vehicles actually like improved fuel economy more than those who prefer smaller vehicles. Finally, the third alternate hypothesis cannot be proved or disproved by *Figure 8.* While some 'size switching' is observed between the Camry, Corolla, and Avalon around November of 2008, no 'size switching' is observed between the same three vehicles around June of 2007. Thus, the data is noisy and no outright conclusions can be drawn in regards to this hypothesis. However, the implicit assumption here is that potential car owners who decide to switch class sizes would switch to a car of the same brand they were considering before, and this assumption may not hold. Thus to fully test this assumption, this study would have to be extended to all vehicle models. To summarize the results from *Figures 5-8*:

1. Small car owners are willing to pay for improved fuel economy. No conclusion can be made whether large car owners are or are not willing to pay for improved fuel economy.
2. Car owners of all class sizes like improved fuel economy.
3. No switching between car sizes is observed between cars of the same brand as fuel price changes, but potential car owners may opt to switch to a car of a different size and brand.

C. The Cost-Benefit Tradeoff of Lightweighting Closures with Aluminum

We have determined the cost premium of aluminum closures by market segment and the consumer willingness to pay for small vehicles in the analyses above. To determine how fuel price influences an automobile company's decision to lightweight vehicles via aluminum substitution, we examined at what production volume consumer willingness to pay for an improved fuel economy of 0.5mpg would be equal to or greater than the cost premium of lightweighting closures to the automobile manufacturer. More specifically, we determined this relationship for the Toyota Corolla (*Figure 9)*. However, it is observed that for a reasonable range of gas prices ($0.90-$8.00/gallon), the consumer willingness to pay for a 0.5mpg increase in fuel would not make up for the extra cost automobile makers would pay to lightweighting closures with aluminum at any production volume. This analysis is of course dependent on cost model assumptions such as material price and labor wage, as well as dependent on the specific vehicle (i.e. the Toyota Corolla in this case).

VI. Conclusion and Future Work

In conclusion, small car owners were observed to be willing to pay for improved fuel economy. However, no conclusion can be made as to whether larger car owners are or are not willing to pay for improved fuel economy. Furthermore, consumer preferences indicate insufficient willingness to pay to cover the costs of lightweighting with aluminum for the specific case of the Toyota Corolla.

Much future work can be done to fully examine the relationship between consumer willingness to pay for improved fuel economy and gas price. For instance, materials other than aluminum can be used for lightweighting closures, and other methods to improve the fuel

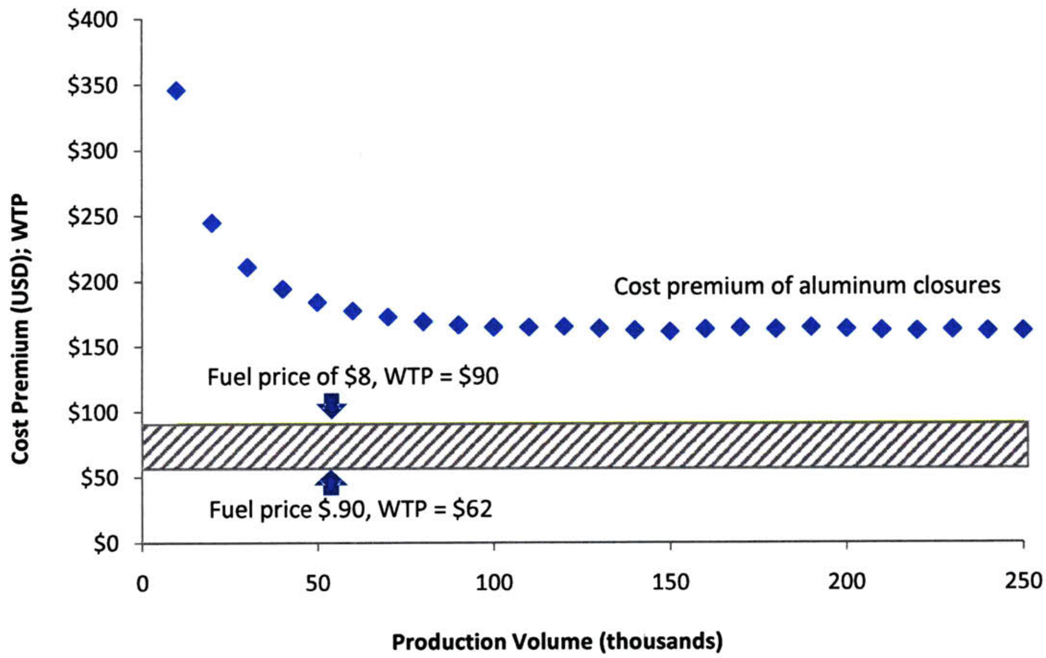

Figure 9: Cost-Benefit Tradeoff of Lightweighting for the Toyota Corolla.

economy of vehicles (such as lightweighting entire vehicle body) exist. In regards to this particular study, further work can be done to examine the relationship between WTP and fuel price for all vehicles available in the market model database. Time restraints prohibited the study of all vehicles, but a more complete understanding of consumer willingness to pay (in particular, if switching between market segments occurs) could be gained from such a study. Also, examining the sensitivity of consumer WTP to different increases in fuel economy as well as the sensitivity of cost premium to different prices of aluminum would help complete the study.

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VIII. Appendices

Appendix A – Details of Closures Scaling

The following details how compact closures were scaled from midsize closures. Large closures can be analogously scaled from midsize closures.

For all vehicle parts,

$$\text{Width of compact closure} = \text{Width of midsize closure} \times \frac{\text{Width of compact car}}{\text{Width of midsize car}}$$

$$\text{Weight of compact closure} = \text{Weight of midsize closure} \times \frac{\text{Curb weight of compact car}}{\text{Curb weight of midsize car}}$$

$$\text{Length of compact closure} = \text{Length of midsize closure} \times \frac{\text{Wheelbase of compact car}}{\text{Wheelbase of midsize car}}$$

$$\text{Blank width of compact closure} = \text{Blank width of midsize closure} \times \frac{\text{Width of compact closure}}{\text{Width of midsize closure}}$$

$$\text{Blank length of compact closure} = \text{Blank length of midsize closure} \times \frac{\text{Length of compact closure}}{\text{Length of midsize closure}}$$

The final surface area of the compact closure is a factor of product of the length and width of the compact closure. Based on previous experience, the factor is estimated to be between 1.1 and 1.3, depending on part complexity. The ratio between surface area and projected area is used to calculate die cost and the predicted cost numbers appear reasonable. Finally, there are no pre-blank costs and the gauge (thickness) of the blanks is assumed to be the same as those of the corresponding midsize parts.

Appendix B – Index of Closure Parts, Forming Processes, and Material Grades

This following forming process and materials were used in cost modeling of compact, midsize, and large vehicles closures.

Closure Part	Forming Process	Material Grade
Front Door	Stamping	Aluminum 6111 (inner)
Inner panel (headerless)	Stamping	Aluminum 6111-T4
Outer panel (headerless)	Stamping	Aluminum 6111 (inner)
Inner beltline reinforcement	Stamping	Aluminum 6111 (inner)
Outer beltline reinforcement	Stamping	Aluminum 6111 (inner)
Modular hinge reinforcement	Stamping	Aluminum 6111 (inner)
Latch reinforcement	Stamping	Aluminum 6111 (inner)
Intrusion beam	Extrusion	Aluminum 6061
Beam bracket	Extrusion	Aluminum 6061
Stiffener	Stamping	Aluminum 6111 (inner)
Hood		
Inner panel	Stamping	Aluminum 6111 (inner)
Outer panel	Stamping	Aluminum 6111-T4
Hinge reinforcement	Stamping	Aluminum 6111 (inner)
Decklid		
Inner panel	Stamping	Aluminum 6111 (inner)
Outer panel	Stamping	Aluminum 6111-T4
Hinge reinforcement	Stamping	Aluminum 6111 (inner)
Latch reinforcement	Stamping	Aluminum 6111 (inner)
Fender		
Front fender	Stamping	Aluminum 6111-T4

Appendix C – Summary of market model runs

The following chart displays the runs for a single week for all trims of the 2009 Chevrolet Aveo. Similar runs were carried out for the other five cars in the case analysis for each week in the two-year span. In each run, either an increase in price or an increase in mpg was tested.

Model: 2009 Chevrolet Aveo					
Trim Level	**LS 4-Door**	**LT 4-Door**	**LT 4-Door AT**	**LT2 4-Door**	**LT2 4-Door AT**
Run 1	+ 0.2 mpg	+ 0.2 mpg	+ 0.2 mpg	+ 0.2 mpg	+ 0.2 mpg
Run 2	+ 0.4 mpg	+ 0.4 mpg	+ 0.4 mpg	+ 0.4 mpg	+ 0.4 mpg
Run 3	+ 0.6 mpg	+ 0.6 mpg	+ 0.6 mpg	+ 0.6 mpg	+ 0.6 mpg
Run 4	+ 0.8 mpg	+ 0.8 mpg	+ 0.8 mpg	+ 0.8 mpg	+ 0.8 mpg
Run 5	+ 1.0 mpg	+ 1.0 mpg	+ 1.0 mpg	+ 1.0 mpg	+ 1.0 mpg
Run 6	+ $50	+ $50	+ $50	+ $50	+ $50
Run 7	+ $100	+ $100	+ $100	+ $100	+ $100
Run 8	+ $150	+ $150	+ $150	+ $150	+ $150
Run 9	+ $200	+ $200	+ $200	+ $200	+ $200
Run 10	+ $250	+ $250	+ $250	+ $250	+ $250

Appendix D – List of statistical tests run in Stata

1. Linear Regressions (y, x)
   a. VNP of model, gas price
   b. VNP of model, gas price with time lags*
   c. VNP of model, change in gas price
   d. VNP of model, change in gas price with time lags*
   e. VNP of model, change in gas price (%)
   f. VNP of model, moving average of gas price
   g. VNP of model, moving average of change in gas price
   h. VNP of model, moving average of change in gas price (%)
   i. Moving average VNP of model, gas price
   j. Moving average VNP of model, change in gas price
   k. Moving average VNP of model, change in gas price (%)
   l. Moving average VNP of model, moving average of gas price
   m. Moving average VNP of model, moving average of change in gas price
   n. Moving average VNP of model, moving average of change in gas price (%)

2. Durbin-Watson Statistics
   Durbin-Watson statistics were found for all regressions.

3. Prais-Winsten Regressions (Cochrane-Orcutt)
   Prais-Winsten Regressions were run for all regressions run.

*One, two, three, four, eight, and twelve-week lags in gas price were examined

**Moving averages for both gas prices and model VNPs are eight-week moving averages

Appendix E – Scaling Results for Aluminum Closures

SA denotes surface area

Extrusion Model Inputs

	Compact Coupe		Midsize Coupe		Large Coupe	
	Intrusion Beam	Beam Bracket	Intrusion Beam	Beam Bracket	Intrusion Beam	Beam Bracket
Material	Al 6061	Al 6061	Al 6061	Al 6061	Al 6061	Al 6061
Part Type	Hollow	Solid	Hollow	Solid	Hollow	Solid
Circumscribing Circle Diameter (mm)	85	70	84.05	69.22	86.21	71.00
Min Wall Thickness (mm)	6	4	6	4	6	4
Piece Length (mm)	1.31	0.15	1.26	0.15	1.36	0.16
Final Part Weight After Fabrication (kg)	1.52	0.20	1.26	0.17	1.71	0.23
Surface Area (sqm)	0.58	0.03	0.54	0.03	0.61	0.03
Number of Bends	0	0	0	0	0	0
Trim Scrap Override	n/a	0.05	n/a	0.05	n/a	0.05

Stamping Model Inputs

ALL VEHICLES	**Material**	**Complexity**	**Finishing**	**Press Type**	**Preblank**
Closure Part		1,2,3			(USD)
Front Door					
Inner panel (headerless)	Al	3	No	Tandem	0
Outer panel (headerless)	Al	3	Yes	Tandem	0
Inner beltline reinforcement	Al	1	No	Progressive	0
Outer beltline reinforcement	Al	1	No	Progressive	0
Modular hinge reinforcement	Al	1	No	Progressive	0
Latch reinforcement	Al	1	No	Progressive	0
Stiffener	Al	1	No	Progressive	0
Hood					
Inner panel	Al	3	No	Tandem	0
Outer panel	Al	2	Yes	Tandem	0
Hinge reinforcement	Al	1	No	Progressive	0
Decklid					
Inner panel	Al	3	No	Tandem	0
Outer panel	Al	3	Yes	Progressive	0
Hinge reinforcement	Al	1	No	Progressive	0
Latch reinforcement	Al	1	No	Tandem	0
Fender					
Front fender	Al	2	Yes	Tandem	0

Stamping Model Inputs, *Continued*

Compact Coupe Closure Part Information	Weight (kg)	Width (mm)	Length (mm)	Projected SA (sqm)	Final SA (sqm)	Gauge (mm)	Width (mm)	Length (mm)
Front Door								
Inner panel (headerless)	3.77	748.52	1394.16	1.04	1.36	1.2	1650.30	978.98
Outer panel (headerless)	2.84	792.37	1401.35	1.11	1.33	1.2	966.55	1562.92
Inner beltline reinforcement	0.90	176.31	1185.55	0.21	0.23	1.6	296.64	1342.39
Outer beltline reinforcement	0.48	170.27	1212.94	0.21	0.23	1.6	252.14	1331.84
Modular hinge reinforcement	0.54	494.40	287.65	0.14	0.16	1.6	642.72	383.54
Latch reinforcement	0.02	80.79	87.51	0.01	0.01	1.6	92.95	105.47
Stiffener	0.21	84.05	407.51	0.03	0.04	2.1	88.99	431.48
Hood								
Inner panel	2.81	1148.03	1476.31	1.69	2.20	1.1	1650.70	1263.76
Outer panel	4.18	1158.99	1482.62	1.72	2.06	1.2	1658.32	1217.74
Hinge reinforcement	0.03	99.85	45.23	0.00	0.00	3	109.60	57.53
Decklid								
Inner panel	2.46	1289.00	535.64	0.69	0.90	1.2	1459.13	1070.07
Outer panel	3.13	1294.84	533.48	0.69	0.86	1.2	1471.52	1088.29
Hinge reinforcement	0.08	223.85	72.09	0.02	0.02	2.5	257.43	82.91
Latch reinforcement	0.08	204.91	67.45	0.01	0.02	2	245.89	84.31
Fender								
Front fender	1.27	724.48	919.09	0.67	0.77	1.2	1339.82	1733.59

Stamping Model Inputs, *Continued*

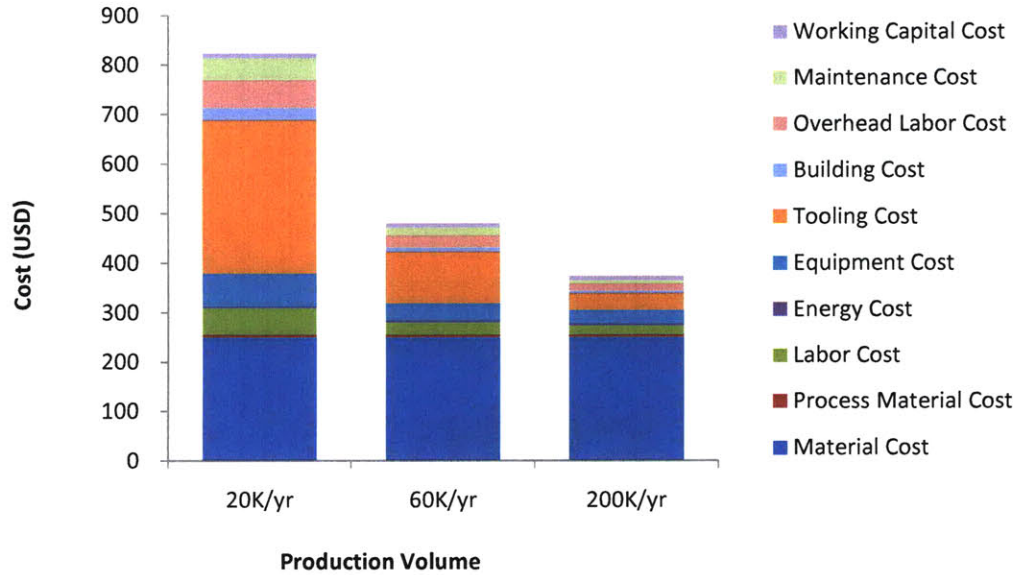
Midsize Coupe Closure Part Information	Weight (kg)	Width (mm)	Length (mm)	Projected SA (sqm)	Final SA (sqm)	Gauge (mm)	Width (mm)	Length (mm)
Front Door								
Inner panel (headerless)	4.54	757.00	1454.00	1.10	1.43	1.2	1669	1021
Outer panel (headerless)	3.42	801.35	1461.50	1.77	2.12	1.2	978	1630
Inner beltline reinforcement	1.08	178.31	1236.43	0.22	0.24	1.6	300	1400
Outer beltline reinforcement	0.57	172.20	1265.00	0.24	0.27	1.6	255	1389
Modular hinge reinforcement	0.65	500.00	300.00	0.15	0.17	1.6	650	400
Latch reinforcement	0.03	81.71	91.27	0.01	0.01	1.6	94	110
Stiffener	0.25	85.00	425.00	1.42	1.57	2.1	90	450
Hood								
Inner panel	3.38	1204.57	1539.68	1.85	2.41	1.1	1732	1318
Outer panel	5.04	1216.07	1546.25	2.59	3.11	1.2	1740	1270
Hinge reinforcement	0.04	104.77	47.17	0.01	0.01	3	115	60
Decklid								
Inner panel	2.96	1352.49	558.63	1.42	1.84	1.2	1531	1116
Outer panel	3.76	1358.62	556.38	1.86	2.33	1.2	1544	1135
Hinge reinforcement	0.10	234.88	75.19	0.03	0.03	2.5	270.11	86.47
Latch reinforcement	0.10	215.00	70.35	0.03	0.04	2	258	87.93
Fender								
Front fender	1.53	732.69	958.54	0.66	0.76	1.2	1355	1808

Stamping Model Inputs, *Continued*

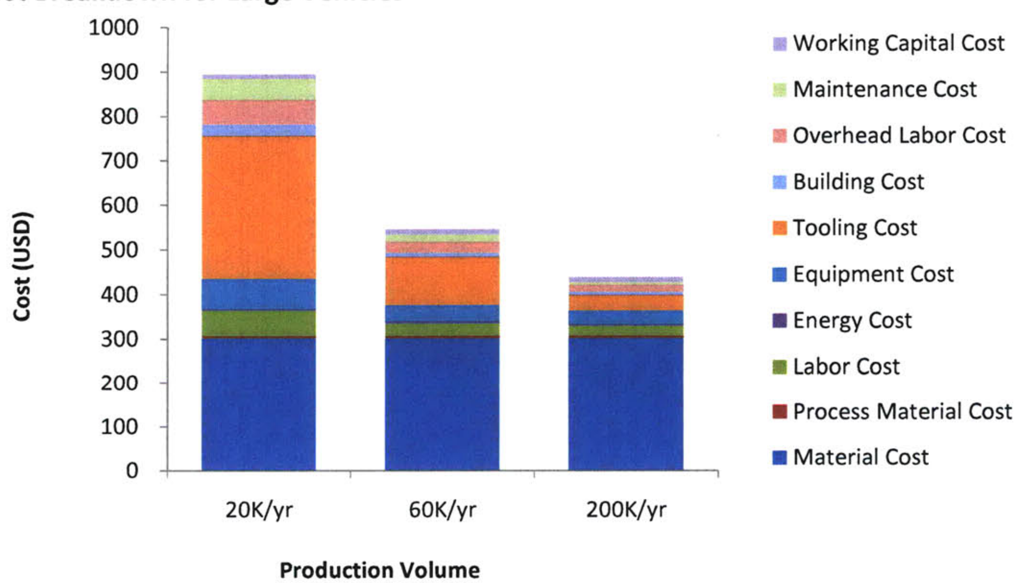
Large Coupe Closure Part Information	Weight (kg)	Width (mm)	Length (mm)	Projected SA (sqm)	Final SA (sqm)	Gauge (mm)	Width (mm)	Length (mm)
Front Door								
Inner panel (headerless)	5.12	767.77	1514.75	1.16	1.51	1.2	1692.75	1063.66
Outer panel (headerless)	3.85	812.75	1522.56	1.24	1.48	1.2	991.41	1698.10
Inner beltline reinforcement	1.22	180.85	1288.09	0.23	0.26	1.6	304.27	1458.50
Outer beltline reinforcement	0.65	174.65	1317.85	0.23	0.25	1.6	258.63	1447.04
Modular hinge reinforcement	0.73	507.11	312.53	0.16	0.17	1.6	659.25	416.71
Latch reinforcement	0.03	82.87	95.08	0.01	0.01	1.6	95.34	114.60
Stiffener	0.29	86.21	442.76	0.04	0.04	2.1	91.28	468.80
Hood								
Inner panel	3.81	1234.52	1604.01	1.98	2.57	1.1	1775.06	1373.07
Outer panel	5.68	1246.30	1610.86	2.01	2.41	1.2	1783.26	1323.06
Hinge reinforcement	0.04	107.37	49.14	0.01	0.01	3	117.86	62.51
Decklid								
Inner panel	3.34	1386.11	581.97	0.81	1.05	1.2	1569.06	1162.63
Outer panel	4.24	1392.40	579.63	0.81	1.01	1.2	1582.38	1182.42
Hinge reinforcement	0.11	240.72	78.33	0.02	0.02	2.5	276.83	90.08
Latch reinforcement	0.11	220.34	73.29	0.02	0.02	2	264.41	91.61
Fender								
Front fender	1.72	743.12	998.59	0.74	0.85	1.2	1374.28	1883.54

Appendix F – Cost Breakdowns for Compact and Large Vehicles

Cost Breakdown for Compact Vehicles

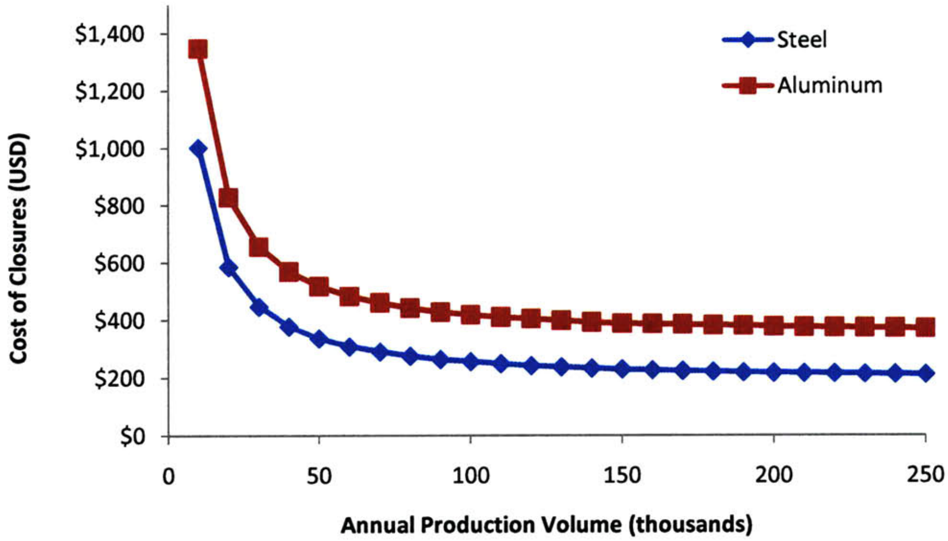


Cost Breakdown for Large Vehicles

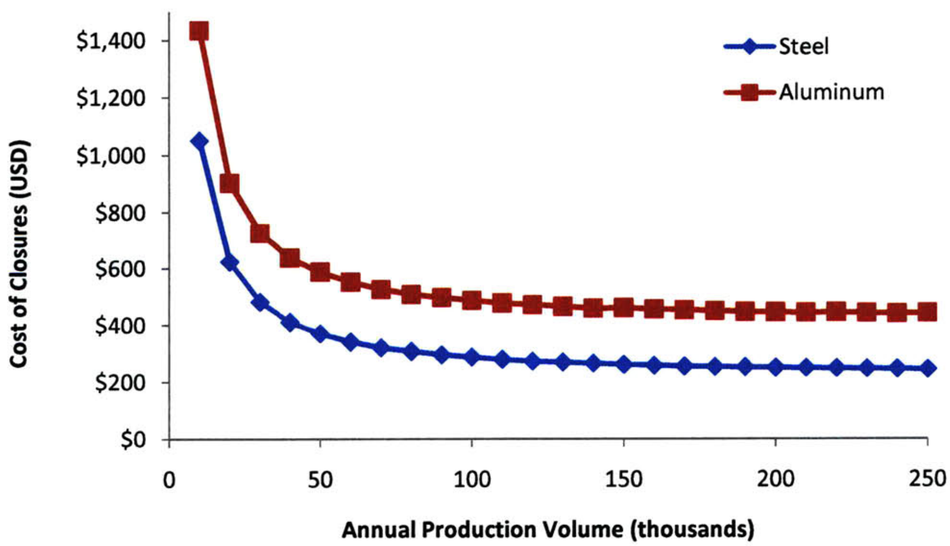


Appendix G – Cost of Forming and Assembling Mild Steel and Aluminum Closures for Compact and Large Vehicles

Cost for Compact Vehicle Closures



Cost for Large Vehicle Closures



Appendix H – Statistical Results

A list of the regressions is available in Appendix D. Moving averages for both gas prices and model VNPs are eight-week moving averages. *NC* indicates no convergence for the Prais-Winsten Regression.

Regression (y, x)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)
	VNP, Gas Price											
Aveo	0.0366	4.56	1.26	0.0391	3.42	2.12						
Malibu	0.0339	3.72	1.28	0.0385	3.00	2.09						
Impala	(0.0013)	(0.05)	1.82	0.0020	0.07	2.01						
Corolla	0.0383	3.61	2.07	0.0430	4.35	1.97						
Camry	0.0121	0.70	1.36	0.0236	1.09	2.03						
Avalon	(0.0173)	(0.51)	1.91	(0.0147)	(0.42)	1.99						
	VNP, Gas Price with One Week Time Lag						**VNP, Gas Price with Four Week Time Lag**					
Aveo	0.0361	4.38	1.23	0.3924	3.32	2.12	0.0279	3.06	1.13	0.0331	2.38	2.17
Malibu	0.0305	3.22	1.24	0.0352	2.61	2.11	0.0146	1.40	1.14	0.0220	1.39	2.14
Impala	(0.0019)	(0.07)	1.83	0.0016	0.05	2.01	(0.0010)	(0.03)	1.83	0.0026	0.08	2.01
Corolla	0.0368	3.38	1.36	0.0120	0.54	2.03	0.0252	2.12	1.91	0.0318	2.65	1.98
Camry	0.0030	0.17	2.05	0.0419	4.10	1.97	(0.0139)	(0.75)	1.35	0.0001	0.01	2.02
Avalon	(0.0237)	(0.68)	1.91	(0.0212)	(0.60)	1.99	(0.0145)	(0.39)	1.91	(0.0121)	(0.32)	1.99
	VNP, Gas Price with Two Week Time Lag						**VNP, Gas Price with Eight Week Time Lag**					
Aveo	0.0345	4.06	1.20	0.0382	3.08	2.14	0.0012	0.13	1.03	0.0076	0.46	2.19
Malibu	0.0262	2.68	1.20	0.0325	2.27	2.11	(0.0146)	(1.36)	1.12	(0.0084)	(0.49)	2.13
Impala	(0.0015)	(0.05)	1.83	0.0023	0.08	2.01	(0.0063)	(0.21)	1.83	(0.0031)	(0.10)	2.01
Corolla	0.0358	3.21	2.00	0.0412	3.84	1.98	0.0010	0.08	1.79	0.0075	0.54	1.99
Camry	(0.0019)	(0.11)	1.35	0.0123	0.54	2.03	(0.0318)	(1.69)	1.38	(0.0169)	(0.69)	2.01
Avalon	(0.0197)	(0.56)	1.91	(0.0168)	(0.47)	1.99	0.0053	0.14	1.91	0.0061	0.15	1.99
	VNP, Gas Price with Three Week Time Lag						**VNP, Gas Price with Twelve Week Time Lag**					
Aveo	0.0315	3.58	1.17	0.0392	2.67	2.15	(0.0199)	(2.14)	1.07	(0.0213)	(1.36)	2.17
Malibu	0.0201	1.98	1.17	0.0248	1.65	2.13	(0.0364)	(3.71)	1.25	(0.0372)	(2.51)	2.08
Impala	(0.0008)	(0.03)	1.83	0.0032	0.11	2.01	(0.0103)	(0.36)	1.83	(0.0092)	(0.29)	2.01
Corolla	0.0309	2.68	1.96	0.0370	3.26	1.97	(0.0178)	(1.49)	1.83	(0.0171)	(1.30)	1.99
Camry	(0.0103)	(0.57)	1.35	0.0009	0.04	2.02	(0.0478)	(2.67)	1.44	(0.0415)	(1.82)	1.98
Avalon	(0.0157)	(0.44)	1.91	(0.0129)	(0.35)	1.99	(0.0046)	(0.13)	1.91	(0.0070)	(0.18)	1.99

Regression (y, x)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)
	VNP, Change in Gas Price											
Aveo	(0.0440)	(0.49)	1.05	(0.0619)	(0.61)	2.16						
Malibu	(0.2277)	(2.36)	1.20	(0.1844)	(1.66)	2.10						
Impala	(0.4244)	(1.57)	1.89	(0.3876)	(1.39)	1.97						
Corolla	(0.0148)	(0.13)	1.86	(0.0003)	(0.00)	2.00						
Camry	(0.3822)	(2.23)	1.43	(0.3038)	(1.62)	2.00						
Avalon	(0.6272)	(1.84)	1.97	(0.6337)	(1.84)	1.96						
	VNP, Change in Gas Price with One Week Time Lag						**VNP, Change in Gas Price with Four Week Time Lag**					
Aveo	(0.0435)	(0.49)	1.05	(0.0261)	(0.26)	2.16	(0.2065)	(2.38)	1.08	(0.1908)	(1.92)	2.14
Malibu	(0.1828)	(1.89)	1.20	(0.1018)	(0.91)	2.10	(0.2935)	(3.13)	1.24	(0.2508)	(2.30)	2.07
Impala	(0.6529)	(2.48)	1.88	(0.6419)	(2.35)	1.96	(0.7387)	(2.84)	1.97	(0.7428)	(2.84)	1.95
Corolla	(0.1435)	(1.27)	1.88	(0.1319)	(1.12)	2.00	(0.1666)	(1.48)	1.91	(0.1523)	(1.32)	1.99
Camry	(0.4667)	(2.77)	1.50	(0.3379)	(1.83)	2.00	(0.6454)	(3.99)	1.65	(0.5267)	(3.02)	1.94
Avalon	(0.3997)	(1.17)	1.96	(0.4038)	(1.16)	1.97	(0.5812)	(1.72)	1.94	(0.5932)	(1.72)	2.96
	VNP, Change in Gas Price with Two Week Time Lag						**VNP, Change in Gas Price with Eight Week Time Lag**					
Aveo	(0.0374)	(0.42)	1.06	0.0679	0.67	2.18	(0.2534)	(-2.89)	1.17	(0.1656)	(1.65)	2.12
Malibu	(0.1364)	(1.40)	1.20	(0.0034)	(0.03)	2.12	(0.3182)	(3.33)	1.36	(0.1946)	(1.77)	2.06
Impala	(0.6001)	(2.27)	1.93	(0.5849)	(2.17)	1.97	(0.4032)	(1.47)	1.84	(0.3683)	(1.29)	1.96
Corolla	(0.1914)	(1.71)	1.89	(0.1832)	(1.58)	1.99	(0.2195)	(1.92)	1.96	(0.2120)	(1.84)	1.98
Camry	(0.4876)	(2.91)	1.50	(0.3804)	(2.08)	1.96	(0.4933)	(2.88)	1.66	(0.2920)	(1.58)	1.96
Avalon	(0.8155)	(2.44)	1.95	(0.8274)	(2.44)	1.97	0.4434	1.27	1.86	0.4775	1.31	1.97
	VNP, Change in Gas Price with Three Week Time Lag						**VNP, Change in Gas Price with Twelve Week Time Lag**					
Aveo	(0.1378)	(1.56)	1.08	(0.0751)	(0.74)	2.16	(0.1698)	(1.52)	1.12	(0.0457)	(0.42)	2.16
Malibu	(0.1899)	(1.96)	1.24	(0.0575)	(0.51)	2.10	(0.3185)	(2.65)	1.24	(0.2351)	(1.94)	2.08
Impala	(0.6766)	(2.57)	1.94	(0.6662)	(2.48)	1.96	0.0662	0.19	1.78	0.1363	0.39	1.99
Corolla	(0.1124)	(0.99)	1.91	(0.0960)	(0.82)	1.99	(0.1154)	(0.80)	1.88	(0.1046)	(0.72)	2.00
Camry	(0.4059)	(2.39)	1.57	(0.1829)	(0.98)	1.98	(0.5917)	(2.78)	1.58	(0.3780)	(1.76)	1.98
Avalon	(0.6769)	(2.00)	1.98	(0.6877)	(2.02)	1.97	0.5258	1.22	1.85	0.5855	1.32	1.98

Regression (y, x)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)
	VNP, Change in Gas Price (%)						**VNP, Moving Average of Change in Gas Price**					
Aveo	(0.3411)	(1.33)	1.07	(0.2815)	(0.94)	2.15	(0.2625)	(2.05)	1.01	(0.2472)	(1.20)	2.08
Malibu	(0.8412)	(3.08)	1.26	(0.6564)	(2.04)	2.07	(0.4375)	(3.19)	1.27	(0.4210)	(2.14)	2.06
Impala	(1.2514)	(1.61)	1.89	(1.1525)	(1.44)	1.96	(1.0909)	(2.92)	1.97	(1.0882)	(2.91)	1.94
Corolla	(0.2701)	(0.82)	1.89	(0.2294)	(0.67)	2.00	(0.3193)	(1.97)	1.92	(0.3116)	(1.85)	2.00
Camry	(1.2544)	(2.56)	1.47	(1.0037)	(1.85)	2.00	(1.0464)	(4.79)	1.66	(1.0421)	(4.05)	2.01
Avalon	(1.5345)	(1.56)	1.95	(1.5360)	(1.54)	1.96	(0.8160)	(1.70)	1.97	(0.8219)	(1.71)	1.97
	VNP, Moving Average of Gas Price						**VNP, Moving Average of Change in Gas Price (%)**					
Aveo	0.0388	3.96	1.09	0.0466	3.12	2.11	(1.0730)	(3.14)	1.06	(1.1316)	(2.12)	2.07
Malibu	0.0294	2.60	1.18	0.0349	2.02	2.14	(1.4278)	(3.88)	1.32	(1.4269)	(2.79)	2.05
Impala	0.0233	0.75	1.86	0.0260	0.77	2.00	(2.9716)	(2.90)	1.96	(2.9746)	(2.92)	1.93
Corolla	0.0345	2.64	1.89	0.0379	2.78	2.00	(1.1617)	(2.65)	1.98	(1.1576)	(2.62)	1.99
Camry	0.0129	0.66	1.35	0.0194	0.72	2.11	(2.9775)	(5.02)	1.69	(2.9796)	(4.35)	2.02
Avalon	0.0054	0.14	1.95	0.0044	0.11	2.00	(1.7477)	(1.32)	1.95	(1.7480)	(1.31)	1.97

Regression (y, x)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)	Alpha	T-Stat	DW Stat	Alpha (Prais)	T-Stat (Prais)	DW-Stat (Prais)
	Moving Average VNP, Gas Price						**Moving Average VNP, Moving Average of Gas Price**					
Aveo	0.0300	6.12	0.10	0.0233	2.39	1.09	0.0332	5.99	0.09	0.0602	5.51	1.27
Malibu	0.0383	8.00	0.11	0.0327	3.42	1.42	0.0307	4.96	0.08	0.0476	3.92	1.39
Impala	0.0113	0.84	0.14	0.0004	0.02	1.72	0.0077	0.51	0.14	0.0085	0.24	1.72
Corolla	0.0336	7.35	0.20	0.0288	2.57	1.93	0.0356	6.74	0.17	0.0532	3.89	2.11
Camry	0.023	2.41	0.09	0.0346	2.00	1.78	0.0035	0.32	0.08	0.0197	0.85	1.80
Avalon	0.0076	0.55	0.19	0.0267	0.82	1.55	0.0057	0.36	0.19	(0.0225)	(0.55)	1.57
	Moving Average VNP, Change in Gas Price						**Moving Average VNP, Moving Average of Change in Gas Price**					
Aveo	(0.0614)	(1.12)	0.09	0.0027	0.15	1.05	(0.1548)	(2.02)	0.09	NC	NC	NC
Malibu	(0.1841)	(3.26)	0.16	NC	NC	NC	(0.4045)	(5.55)	0.12	NC	NC	NC
Impala	(0.1809)	(1.37)	0.15	(0.0159)	(0.27)	1.75	(0.8763)	(5.31)	0.17	(0.4916)	(1.81)	1.83
Corolla	(0.1138)	(2.11)	0.20	0.0412	1.73	1.91	(0.2541)	(3.47)	0.17	0.1962	1.68	1.97
Camry	(0.1468)	(1.54)	0.12	0.0299	0.89	1.83	(0.6852)	(5.89)	0.13	(0.1224)	(0.74)	1.79
Avalon	(0.1043)	(0.75)	0.19	(0.0385)	(0.54)	1.56	(0.7973)	(4.48)	0.20	(1.0760)	(3.46)	1.72
	Moving Average VNP, Change in Gas Price (%)						**Moving Average VNP, Moving Average of Change in Gas Price (%)**					
Aveo	(0.2854)	(1.82)	0.11	NC	NC	NC	(0.6318)	(3.09)	0.10	NC	NC	NC
Malibu	(0.7382)	(4.81)	0.24	NC	NC	NC	(1.2964)	(6.89)	0.12	NC	NC	NC
Impala	(0.7361)	(1.96)	0.16	(0.0248)	(0.14)	1.75	(2.4843)	(5.54)	0.18	(1.6502)	(2.05)	1.84
Corolla	(0.4681)	(3.10)	0.25	0.1411	1.92	1.93	(0.9238)	(4.83)	0.19	0.4523	1.25	1.95
Camry	(0.6588)	(2.45)	0.14	0.0928	0.89	1.81	(1.9793)	(6.32)	0.13	(0.5547)	(1.09)	1.79
Avalon	(0.6432)	(1.63)	0.20	(0.1468)	(0.66)	1.56	(2.2500)	(4.64)	0.20	(3.1483)	(3.36)	1.73