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Green-Technology Automobiles: Can modern innovations save the environment and consumers' pockets

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Abstract

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Keywords

Hybrid, Car, MPG, Vehicle, Automobile, Innovations, Green Technology, Fuel Efficiency

Disciplines

Environmental Education | Environmental Health and Protection | Environmental Sciences | Oil, Gas, and Energy | Sustainability

Comments

Environmental Studies Thesis

Green-Technology Automobiles:

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ES 400 The Impact of the Automobile on Culture and Environment

Professor Rutherford Platt

Abstract

Cars of the past are notorious for poor fuel efficiency and high carbon emissions. With the presence of hybrid technology, along with a variety of other green innovations, many of these negative side effects can be mitigated. The purpose of this study is to answer the question: how do green technology vehicles compare with similar models that exclude such innovations in relation to efficiency and price? A total of 47 green-tech vehicles were identified and compared against their base model counterparts. Vehicle weight, horsepower, fuel efficiency and other variables were matched within pairs (green-tech vs. base) and between car types (sedans, SUVs and trucks). Regardless of vehicle type and green-tech, weight proved to be an influential factor, showing that as curb weight increased, fuel efficiency decreased. Compared to the base models, green-tech luxury vehicles also exhibited few improvements in fuel efficiency with disproportionately high growth in price. Non-luxury green-tech sedans ranging from 2500lbs to 4000lbs showed the largest improvements in efficiency while also maintaining an average MSRP of \$28996±1089, producing a green-tech vehicle that is economically affordable. The impressive results from this category of vehicles suggest that consumer investment in non-luxury green sedans may not only help to save money in fuel consumption, but also save the environment.

Introduction

The revolution of the combustible engine reshaped America into an automobile culture, introducing a vital means of automotive transportation since the dawn of Henry Ford's Model T in 1908. With the incorporation of innovations and technologies like interchangeable parts, flexed suspension, and light vanadium metals, Ford forged a path for more modern ideas to enhance the basic car. During the Roaring Twenties, Model T sales peaked at 1.8 million cars along with an increased desire for other automotive companies to compete against Ford's success by utilizing innovative technologies to improve the car (Ingrassia 2010). Over a century later, innovators and engineers continue to boost the mechanical performance of vehicles. The United States Environmental Protection Agency (EPA) has shown the automobile's designs and mechanics have trended over the past quarter century toward more efficient fuel technology in automobiles, including the use of alternative fuels in hybrid and diesel engines (Alson et al. 2013). Technologies that enable cars to be more efficient while producing similar, if not more, power include transmission types, full electric operation, hybrid technology, forced induction, altered engine design, reduction in weight, alternative fuels, and brake regeneration. Some of these technologies are still in their infancy, but as society continues to push towards more fuel-efficient vehicles, they will ultimately evolve into key aspects of innovative cars.

Automated Manual Transmissions (AMT) are a key component to the operation of automobiles, using a set number of gears to transfer the power created by the engine to the wheels for operation; the more gears, the more efficient the vehicle. Continuously Variable Transmissions (CVT) differ from this because they utilize a pulley system that results in infinite gear ratios. Full electric operation is another innovative alternative to increase efficiency, using rechargeable batteries to power electric motors connected to the wheels directly. Consequently, full horsepower and torque are always available, unlike gasoline engines where high engine rotations (rpm) are needed to achieve full power. Hybrid technologies have recently become popular in today's pursuit for increased efficiency and power output due to the utilization of electric motors concurrently with gasoline engines to produce a combined power output. Forced induction is also a very popular way to achieve increased MPG standards and power output, while reducing engine size and fuel consumption. Turbochargers use spent exhaust gasses to power an induction turbine that forces a greater amount of oxygen into the cylinders, thus creating a more powerful detonation in the cylinders. Superchargers differ because the engine belt powers the turbine, but operate in the same function as turbochargers by forcing a greater amount of oxygen into the cylinders. Additional factors that help increase efficiency standards include the utilization of weight saving materials like certain alloys and composite materials in order to reduce the demand on the engine.

Most recent innovations involve engines becoming extremely advanced and use multiple technologies to increase its capabilities while maintaining efficient operation. Such innovative engine technologies that have been incorporated in many cars are cylinder deactivation, start-stop technology, variable valve timing (VVT), and direct injection. Cylinder deactivation is the process in which fuel is shut off to certain cylinders under low rpm conditions where power is not needed for operation. Start-stop technologies focus on shutting the engine off while at a full stop, but restart the engine once pressure is removed from the brake pedal. This prevents unnecessary fuel burning while at stoplights. VVT and direct injection are both methods used to ensure maximize fuel output during the compression and power stroke of the pistons. VVT is the process where intake and exhaust valves open to allow oxygen and exhaust gasses to enter and leave the cylinder during the induction and exhaust stokes. Direct injection correlates with this process for it directly injects gasoline, as a mist, into the combustion chamber (cylinder), allowing for a complete burn and detonation of the gasoline in the compression and power stroke, resulting in more power and efficiency. Specific fuel used during these stages also plays a vital role in the efficiency and power of vehicles, with diesel engines roughly 30-35% more fuel-efficient than gasoline counterparts. Innovations like these are key to the development of automobiles for they help reduce our global emissions impact, while maintaining the forward progress in the American automotive industry.

Since the turn of the century, America's automobile culture has conflicted with government policies that voice concern for the carbon emission impact that follows the predicted rise in travel intensity. On a global matter, the IPCC in 2008 issued a crucial report on the current trend in environmental conditions and that further contributions of carbon emissions and other Greenhouse Gases (GHGs) will induce a warmer climate with a multitude of repercussions. With this in mind, if we relate America's carbon emissions on a global scale, strictly using only the GHG produced by vehicles, then the total US transportation fleet emits a quantity larger than the total national GHG emissions from all other countries with the exception of Russia and China (Schäfer 2009). This sounded an alarm for American policy managers to institute mitigation measures on a national scale that reduced the 1.7 billion tons of GHGs already produced by automobiles each year (Vehicle Technologies Office 2014). By 2010, America's federal government introduced the nation's first ever mileage standards directed specifically at automobiles. The National Fuel Efficiency Policy required automotive companies to manipulate vehicle designs in order to generate better gas mileage with the highest possible fuel efficiency, thus lowering carbon emissions and other GHGs to the atmosphere (House 2009).

The combination of environmental concern and continuation of improving vehicle technologies has led to the introduction of "green technologies," which have been recognized as powerful components to stimulate higher standard fuel economy outputs, some of which even meet CAFÉ standards of 54.5 miles per gallon (MPG) proposed by the Obama Administration for the year 2025. These green technologies have even recently expanded to "gas guzzling" sports utility vehicles (SUVs), as seen in the 2014 Washington Auto Show, where hybrid, clean diesel, and high efficient SUV models were finalists in the Green Car Technology category. Regardless of the technical progress and designs found in today's automobiles, vehicle manufacturing companies, from large corporations like General Motors to privately owned businesses like Tesla Motors, are showing a trend in chasing a similar goal: design a car that increases fuel efficiencies and mechanical performance, while being environmentally popular to the automotive market.

In our study, we have compiled a fleet of standard model vehicles and their "eco-friendly" counterparts, which include green technologies into the standard model design. Our research question asks "what latest technologies and innovations exist in the most recent models to improve efficiency in mechanical performance through a comparison with vehicles that exclude so called green, eco-centric technologies?" Previous reports, like the EPA's Trends Report, were similar to our study for it focussed on innovative technologies and their implications. The purpose of the EPA's Trends Report was to "...present technical analysis of issues using data…" and formulate reports to "facilitate the exchange of technical information and to inform the public of technical developments" (Alson, Hula, Bunker 2013). This supports our study because we sought to determine how the latest technological innovations affect vehicle performance and capability in newest models. However, we sought to further our focus and determine how to best spend consumer money on these vehicles in order to achieve the best efficiency for the most reasonable price.

This analysis evaluates vehicle models across 3 different vehicle classes as well as an assessment between luxury and non-luxury models. These environmental implementations to automobiles have altering effects on price, which may be a deterrent to purchasing models with specific green-technologies. In doing so, base models (cars containing a traditional gasoline engine with no innovation) and green-tech models (cars containing innovations) are distributed by companies, for the public to purchase.

Methods:

Identifying Car Pairs

Car comparisons were identified between green-tech models that contained at least one technological innovation that its base model counterpart did not contain. To provide a simple example, the Toyota Camry would be a base model while the Toyota Camry Hybrid would represent the green-tech model. Environmental innovations included technologies like: transmissions, full electric operation, hybrid technology, forced induction, engine design modification, weight saving materials, fuel altering, or brake regeneration. Vehicles containing at least one of these innovations was considered a green-tech vehicle. Additional criteria included vehicles that represent newest models. Older year car models were only used if a base vehicle was not available for the year 2014 or 2015. A base car usually consists of a combustible gasoline engine, with no specific engine development. These cars also will lack innovations as stated above, however if they do contain such listed technologies, they will be substantially less developed as their green counterparts. To achieve the most accurate comparisons we attempted to find cars that only differed in environmental innovations while remaining aesthetically identical. This provided comparisons that only showed the significant effects from adding the innovative technology.

Data Collection

The most important data for each comparison was the Manufacturer's Suggested Retail Price (MSRP) along with other various performance statistics, which were compiled onto an excel spreadsheet. These performance statistics included city and highway fuel efficiency, horsepower, torque, curb weight, transmission speed, and drag coefficient. The most important and relevant green-tech innovations that were common throughout the study were listed and identified in a table.

The data collected for this study was obtained by using reputable sources that focus heavily on the car industry. The specifications for each car were mostly obtained through car manufacturer's websites, where they are required to display information relating to the specific model. This was the location in which the majority of our data was gathered. However, not all of the manufacturers websites contained the necessary data needed to fulfill our data spreadsheet. The additional data needed was gathered through other online sources like Cars.com, EdMunds, MotorTrend, and Car and Driver. These websites proved to be legitimate sources for they are third party automotive website evaluators, with Edmunds, for example, receiving the award for being the best evaluator of new and old cars. These websites not only provided missing data for current cars, but also for older models where the manufacturer websites no longer contained the information. Additionally, these websites helped to explain the innovations that are currently in use by the cars, which is necessary for people who do not fully understand the inner workings of automobiles. These websites also served as valuable resources for car pairs for they rank the top green cars each year.

Data Analysis

Data analysis was performed to determine the top technologies that increase efficiency while remaining economically reasonable. We first compared all green-tech models to the base model counterparts. Histograms were created to compare all variables and provided means and standard error between vehicle statistics. Statistical differences for comparing all vehicle base models to green-tech models were determined by using a t-test measuring pair two sample for means. As stated previously, these statistical analyses included price, horsepower, torque, curb weight, city and highway fuel efficiency, transmission speed.

Differentiations were created by separating the vehicles into car types that included: Sedans, SUVs, and Trucks. Again, histograms were created to compare all variables within each car type. One-way ANOVA statistical tests were used to determine statistical significance between the variables. Further differentiations were analysed by separating luxury from non-luxury models. A scatterplot was also created for all vehicles to show the change in price and change in city fuel efficiency.

While analyzing the data we experienced a few limitations that required us to make compromises. One such limitation was the availability of information regarding certain cars, specifically some of the newest models. Some manufacturers did not disclose the new models specifications, which forced third party sources to be used for the missing data. Another limitation was the disagreement of data between two sources, which was solved by utilizing the more legitimate source. Cars sold to certain countries also posed as a limitation due to the fact that certain models were constrained to only a few countries for they did not meet certain specifications that allowed sales in outside countries.

Results:

All Vehicles

When comparisons were analysed across all vehicles, the green-tech models had an average price of $47,463.98±3,540.36 while the base models had an average price of $40,728.78±2931.17 (table 1). This shows the average green-tech vehicle is $6,735.20 more expensive that the base model counterpart (table 2). The p-value for this comparison was 0.00, which implies there is a statistical difference between the price comparisons (table 3).

Although price was seen to increase by a significant amount, the performance of the green-tech models was also seen to increase compared the base models in terms of fuel efficiency, horsepower, torque, transmission speed, and curb weight (figure 1). Horsepower and torque increased by an average of 12.67 and 39.62, respectively, with a torque p-value comparison of 0.001. Fuel efficiency in the city proved to gain more between the green-tech vehicles and the base models than fuel efficiency on highway. Green-tech models experienced an average increase in city fuel efficiency of 7.43 MPG while average highway efficiency increased by 5.55. The p-values for these comparisons were 0.004 and 0.002, respectively (table 3). Both of these values show statistical significance.

There was also a comparison between the change in price and the change in city fuel efficiency for each individual car comparisons. A total of 4 vehicles within our study showed increases in fuel efficiency and decreases in price, representing technology that benefited the consumer. Additionally, total of 6 vehicles in our study showed an increase in price and a decrease in fuel efficiency, representing technology that hurts the consumer and the environment (figure 2).

Sedans

Sedans showed the largest increase in price with the average green-tech sedan costing 48558±5874 and the base sedan costing 37,080±5462 (table 4). This showed an average increase of

$11,478 (table 5). Green-tech sedans also showed comparative increases across all performance specifications: horsepower, torque, transmission speed, curb weight and fuel efficiency (figure 3). However, green-tech sedans showed the best improvement to overall fuel efficiency when compared to the relative base models. They increased city fuel efficiency by an average of 13 MPG, with the standard model averaging 26±2 MPG and the green-tech model averaging 39±5 MPG. In terms of highway fuel efficiency, base sedans averaged 34±2 MPG while green-tech models averaged 41±3, creating an increase of 7 highway MPG (table 4 and 5).

The green-tech sedans were then compared to base sedans on a scatterplot by using city fuel efficiency and weight, providing green-tech sedans with an R^2 value of 0.54 compared to a base sedan R^2 value of 0.30 (figure 5). Green-tech vehicles ranging from 2500 pounds to 4000 pounds showed the most effective increases in city MPG compared to their base models. For example, the Toyota Camry and the Camry Hybrid weigh 3240 lbs and 3485 lbs, respectively. The hybrid increases the city fuel efficiency by an impressive 18 miles, bringing it from 25 to 43 MPG in the city with an increase in price of $5,000 above the base model.

Environmental innovations in vehicles have been shown to affect other areas of performance apart from fuel efficiency. Horsepower, torque and transmission speed are all aspects of the vehicle's mechanical performance that are influenced by the presence of a green technology. Specifically, green-tech sedans showed an average increase of 9hp being added to their base model counterpart, while the torque in green-tech sedans increased by an average of 34 lb/ft. Higher transmission speeds are also related to the efficiency a vehicle. For this reason, these comparisons between green-tech cars and base models were taken into consideration. Green-tech sedans showed an average increase in transmission speed of 0.4 (table 5).

SUVs

Green-tech SUVs experienced an increase in price of $8,621 being added to the comparative base model (table 5). Performance specifications between green-tech SUVs and base model SUVs also showed differences. Green-tech SUVs showed comparative increases across all performance specifications: horsepower, torque, transmission speed, curb weight and fuel efficiency (figure 3). SUVs experienced an average increase of 3 MPG for both city and highway efficiency. The horsepower of green-tech SUV's only gained an average of 5hp in comparison to the base model counterpart (table 5). However, the presence of a green technology was shown to have inconsistent effects on different companies and models within the SUV category, especially within horsepower performance. For example, the BMW X5 and its comparative base model showed a gain of 145hp, increasing from 300hp to 445hp. The presence of this innovation and the increase in horsepower will cost the consumer an additional $13,600. However, other vehicle models showed a different outcome. The Porsche Cayenne experienced a drop in horsepower from 420hp to 240hp when the base model was compared to the environmentally friendly diesel model. Despite the drop in power performance, the presence of the green technology will cost an additional $3,400 while only improving city fuel efficiency by 3 MPG.

SUV's experienced the largest gain in torque with an average increase of 57 lb/ft between the green-tech model and its base model counterpart. Green-tech SUVs also increased their average transmission speed over the base model by an average 0.2 (Table 5).

Trucks

Green-tech trucks experienced the lowest average increase in price with $2,146 being added to the comparative base model (table 5). Green-tech trucks showed increases across all performance specifications: horsepower, torque, transmission speed, curb weight and fuel efficiency (figure 3). However, the green-tech trucks only managed an average increase in highway and city fuel efficiency of 0.4 and 0.9 MPG, respectively. Weight has a large influential factor on the vehicles fuel efficiency improvement, even if the car contains modern green technology. Cars that were high in weight, which included all trucks, showed little differentiation between the MPG of the green-tech model and the base model. For example, the Ford F-150 and its eco-friendly counterpart both weigh over 5000 pounds. Although the twin-turbo option is intended to decrease the environmental impact, it only increases the vehicles fuel efficiency by 1 MPG, increasing from 15 to 16 MPG in the city. Furthermore, deciding to purchase the twin turbo model would cost almost $2,500 more than the base model counterpart. At this rate, it would take over 200,000 miles of driving in order to pay off the cost of the innovation in gas savings.

When graphing the vehicle curb weight of the green-tech trucks and the base models against their relative city fuel efficiency, another relationship emerged. Visually, there did not appear to be any differentiation between the trend-lines of the green-tech and base models. The R^2 value of green-tech trucks is 0.35 while the R^2 value of base trucks is 0.41 (figure 5). Environmental innovations in trucks have been shown to affect other areas of performance. Trucks showed an average increase of 14hp between the green-tech model and the base model, while also increasing by an average of 33 lb/ft of torque. Higher transmission speeds are also related to the efficiency a vehicle and trucks showed there was an average increase in transmission speed of 0.5 (table 5).

Luxury vs. Non-Luxury

However, when differentiating between luxury and non-luxury vehicles there were notable differences. Luxury green-tech vehicles had an average cost of 70,361±4,939.86 while the base models had an average price of 60,781±3564.50 (table 7). This averaged a price increase of $9,580 above the base model (table 8). Non-luxury green-tech models had an average cost of 32,744±1983.62 while non-luxury base models had an average price of 27,838±1628.99 (table 9). This showed an average increase of $4,906 above the base model (table 10). For example, the Lexus LS base model has an MSRP of $72,520 while the Lexus LS Hybrid has a suggested retail price of $120,440, a $47,920 difference. Furthermore, non-luxury green-tech vehicles showed an average improvement in city fuel efficiency of 10 MPG and an highway improvement of 7 MPG above the base models, while Luxury green-tech vehicles were only able to achieve an improvement in city fuel efficiency of 4 MPG and a highway improvement of 2 MPG above the base models.

The change in curb weight was also shown to vary between luxury and non-luxury comparisons. Non-luxury green-tech vehicles had an average increase of 210 lbs compared to the base models while luxury green-tech vehicles had an average increase of 347 lbs above the base models. Horsepower also proved to be an interesting comparison with luxury green-tech vehicles experiences a decrease of 1hp compared to the base luxury models while non-luxury green-tech vehicles showed an increase of 22hp.

Discussion

After analyzing the data from our vehicle comparisons of base models to green-tech models, we find that the incorporation of innovations to automobiles improves all variable car components. Statistically speaking, the effects of specific variables, including torque and curb weight, may provide reasons to statistical significances in other car components more relevant to the average consumer, specifically price and fuel efficiency. Even though our results provided statistical insignificances within car types, we observe the biggest differences in price, torque, and fuel efficiency among sedans and SUVs. Given that luxury models experienced the greatest increases in price, we expected to find the greatest improvements to variable car components, however, the greatest differences were actually found across non luxury models. Additionally, our data provides evidence that the variable component of horsepower decreases in luxury models, which may explain why horsepower across car types and all vehicles show the highest insignificance values. Interestingly, we find this similar pattern with torque, providing insignificant values when compared across car types, but within all vehicles, particularly luxury models, torque significantly increases between base models and their green-tech counterparts.

In reference to the consumer, price is a large component in determining which vehicle suits a person's individual lifestyle. When we compare the differences in price to fuel efficiency of base models to their green-tech counterparts, we find two key aspects; 1) innovations that cost less but allow the consumer to drive further distances and 2) certain models we identified as green-tech are actually failures in providing better fuel efficiency but increase in price. Models that we found to decrease in price but raise fuel efficiency include Toyota Tundra, Mercedes Benz GL 450, Buick Regal Hybrid, and Acura RLX Hybrid. There is no definite explanation we have for this other than the company potentially lowered their prices in order to entice a greater consumer demand. The models we found as "green-tech failures" include BMW 5 Series Hybrid, Volkswagen Jetta GLI, Honda Civic (natural gas model), Nissan Frontier, Nissan Titan, and Toyota Tacoma. This is particularly interesting in regards to the natural gas models since it is an alternative fuel to oil. Although we would expect higher efficiency ratings like we find in diesel models, Schafer et al. (2009) explains this phenomena by showing oil products store the largest amount of energy per unit weight in comparison to all other alternative fuels. Therefore, the Honda Civic natural gas model, compared to its base model, compensates for its lack of fuel efficiency through lower carbon emissions.

When reviewing the results regarding sedans, trucks, and SUVs there were noticeable discrepancies between base models and green-tech models in regards to MPG, torque, price, and weight. Though not proven statistically significant, sedans and SUVs visually show the greatest difference in these values when compared to the truck class.

Sedans and SUVs showed a linear relationship between price and weight and can be attributed to the fact that green-tech models contain innovations that increase both weight and price, when compared to base models. The weight increase can be explained by the addition of innovative technologies onto the vehicles frame, which increase the original vehicles weight (figure 3). The price increase between base and green-tech models was especially apparent in the sedan and SUV category, most likely due to the expense of the innovation being added to original vehicle price.

Weight plays a significant factor in the overall vehicle efficiency, and can be seen to have an inverse relationship (figures 5 and 6). As weight increases, the efficiency standards decrease. The increase, attributed to the addition of innovative technologies, affects the overall efficiency of the vehicles. However the benefits of the added innovation outweigh the additional weight; as seen in figure 3, where increases in sedan and SUV MPG is apparent between the base and green-tech models.

SUVs and Trucks tend to have worse efficiency standards when compared to sedans, and can credited to the increase in vehicle weight, drag coefficient and engine size. Greater engine power provides increased capabilities and increased power to run vehicle accessories. Since SUVs and trucks are large vehicles, they can accommodate more accessories (entertainment systems, navigation systems, climate control, additional seats, etc.), which add to the overall weight of the vehicle. In order to cope with the additional weight, larger displacement engines are used to maintain performance capabilities, thus adding to the reduced efficiency standards (Shafer et al., 2009). When comparing the base models to their counterparts, little improvement is achieved when innovative factors are added and can most likely be explained by these vehicles high drag characteristics.

Sedans reign supreme in having the maximum efficiency standards when compared with the larger vehicles, but they too show similar characteristics in weight and efficiency. As vehicle weight increased, MPG decreased (Figure 5 and 6). This can be explained by the addition of similar accessories from above. The weight discrepancy between base and green-tech models show little increase, again most likely caused by the implemented innovation. However, when compared to the larger vehicles minor increase in innovation efficiency, sedans showed massive gains in MPG standards. The added innovations proved to have great benefits for they slightly increased the weight, but were able to return increase MPG standards.

These innovations additionally increase torque output of sedans, trucks, and SUVs when compared to their base counterparts. This can be attributed to the use of diesel fuel in some green-tech models, for diesel contains more energy per volume than regular gasoline (Shafer et al., 2009). SUVs, however, showed significant results in torque increase between base and green-tech models.

Innovative technologies like hybrid drivetrains can explain this result because the electric motors apply additional power to the SUV. Vehicles like the Nissan Pathfinder and Porsche Cayenne are examples of this relationship, and are able to reduce engine size while increasing the overall torque from the base model.

Luxury green-tech vehicles represented a category of cars within this study that were especially disappointing. For an average of nearly $10,000 dollars more compared to the base model, luxury green-tech vehicles further displayed a decrease in horsepower (-1hp) and poor increase in fuel efficiency (+2 highway MPG). For such a high increase in price, one would expect to see an equally impressive increase in efficiency. There are several specification factors that could be noted for these poor results. First, the luxury green-tech models displayed a higher increase in weight compared to the base models than the non-luxury green-tech vehicles, averaging well over one hundred pounds of additional weight. This increased weight can be accounted for by the added amenities and green-tech (such as hybrid batteries) in some models that accompany the increase in price. This result is further justified by our scatterplots comparing weight to fuel efficiency, showing that heavier green-tech vehicles have smaller improvements in fuel efficiency when compared to lighter vehicles. Another factor can be related to the transmission speed within the luxury green-tech category compared to the base models. With zero increase in overall transmission speed, this is another area that could have benefitted the vehicle's efficiency but showed no improvement.

Some luxury green-tech models showed an increase in overall performance specification that would also result in less significant increases to fuel efficiency. Again, the Lexus LS Hybrid can serve as an example. Although this represents the luxury green-tech vehicle in the comparison to its base model, it contains a larger 5.0-liter engine that requires more fuel, further degrading the ability to increase fuel efficiency. The difference between the LS Hybrid and its base model was shown to *decrease* by 1 MPG in terms of highway efficiency despite its enormous increase in price.

Many green-tech luxury vehicles and the base model counterparts that lack in fuel efficiency have been imported from European countries. Historically, this category of vehicle has been hurt by past CAFE standards to the point where the European Union tried to file lawsuits that the standards were discriminatory against European countries (Vig and Kraft 2006). However, they did not win in court and are still held to equal standards. Unfortunately, our results suggest these luxury vehicles will continue to have a hard time complying with the future CAFE standards that are becoming increasingly harder to achieve.

Once we began to analyze the vehicle comparison data, our limitations clearly showed a trend in data collection, particularly transmission speed. We were unable to perform statistical analyses to numerically show continuous variable transmission (CVT) as a green-tech because the innovation is designed to combat the energy loss found in traditional transmission gears. However, we suggest that this green-tech does provide increases in mechanical performance because none of the vehicles we label as “failed green-tech” incorporate this type of transmission. Another limitation to our analysis was the overall n-value used for car comparisons. Once comparisons between base and green-tech models were analyzed across both car types and luxury relationships, our results provided insignificant differences even though our data clearly shows a visual trend in enhanced mechanical performance, particularly price and fuel efficiency. This suggests future studies on vehicle comparisons should provide a large enough n-value to make comparisons across all sub categories in reference to automobiles.

Based on our research, we were able to support the increasing trends in fuel efficiency of automobiles found by the 2013 EPA Trends Report. However, we were unable to answer whether these technological innovations are able to affect carbon emissions because motor companies only provide a qualitative emission rating based on the EPA’s approach for setting categorical standards. Therefore, future studies should focus on how these green-tech vehicles compare to their base models using quantitative emissions data. We also suggest observing how drag coefficient affects the mechanical performance of a vehicle. Many of the motor companies within this study, particularly American manufacturing companies, were reluctant to provide source data on this variable. This would be interesting as well because the few data references we were able to collect drag coefficient from show the highest drag in trucks and the lowest in sedans. Future research on this study may be able to correlate this factor to fuel efficiency.

Conclusion:

Throughout history we have seen the automobile gradually develop into a more advanced piece of technology, whether it's increasing power, safety, or usability. However the past decade has focused largely in developing innovations that increase power and efficiency. The purpose of this study was to see the relationship between base model cars and their green counterparts, and whether or not it is worth purchasing the green-tech model. After gathering roughly 47 paired models from different manufacturers and gathering the corresponding data, we came to the conclusion that weight was a statistically significant factor in regards to fuel efficiency, and that heavier cars tend to have decreased efficiency standards. Additionally, it was determined that green technologies implemented in cars had an effect in increasing the efficiency in both city and highway miles. However, drag remained nearly constant between each pair, and is theorized that it would increase manufacturing costs to develop more aerodynamic vehicles. When reviewing luxury vehicles, it was determined that it would not be financially beneficial to invest in one, for they provide little increase in efficiency when compared to non-luxury models that have much higher increases.

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Appendices

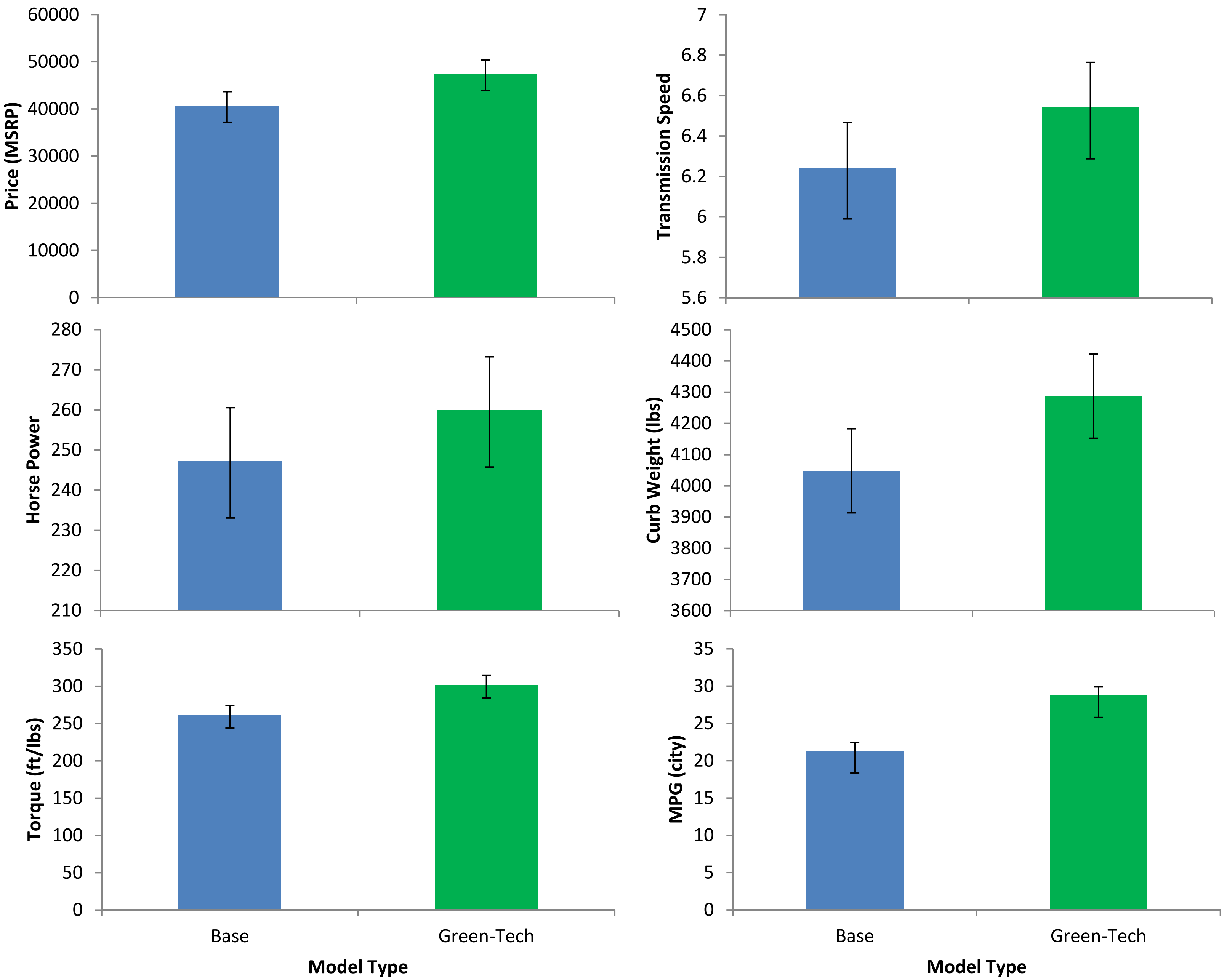

Figure 1: Histogram shows the average (arithmetic mean), with standard error bars, of all vehicles within the study, comparing the base model (blue) to the green-technology model (green) across the variable components of price (MSRP), horsepower, torque (feet per pounds), transmission speed, curb weight (pounds) and miles per gallon (MPG) city.

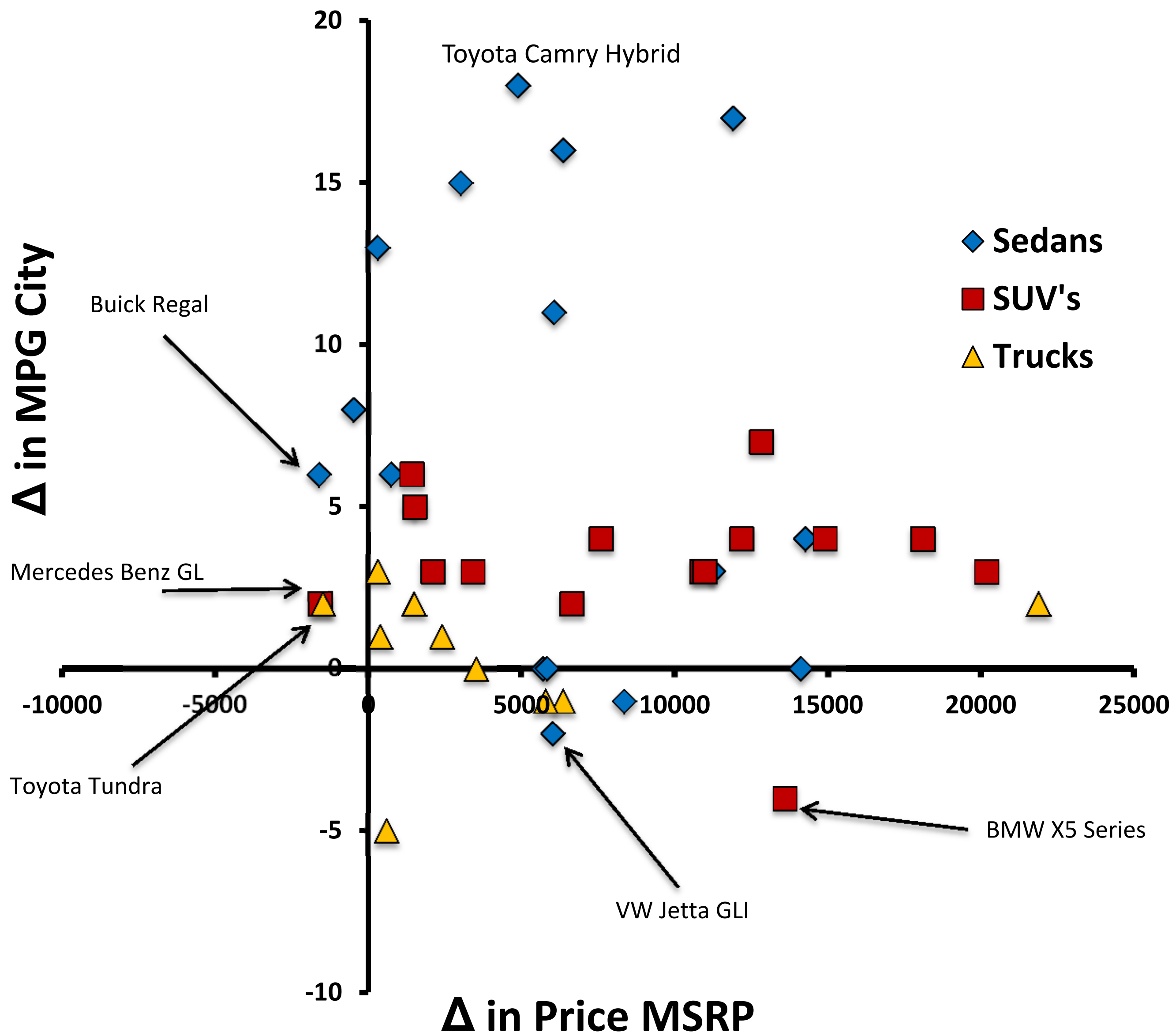

Figure 2: The relationship between the change in miles per gallon (MPG) city and change in price (MSRP) of all vehicles, comparing the base model to the green-technology model with the equation GreenTech – Base = Δ.

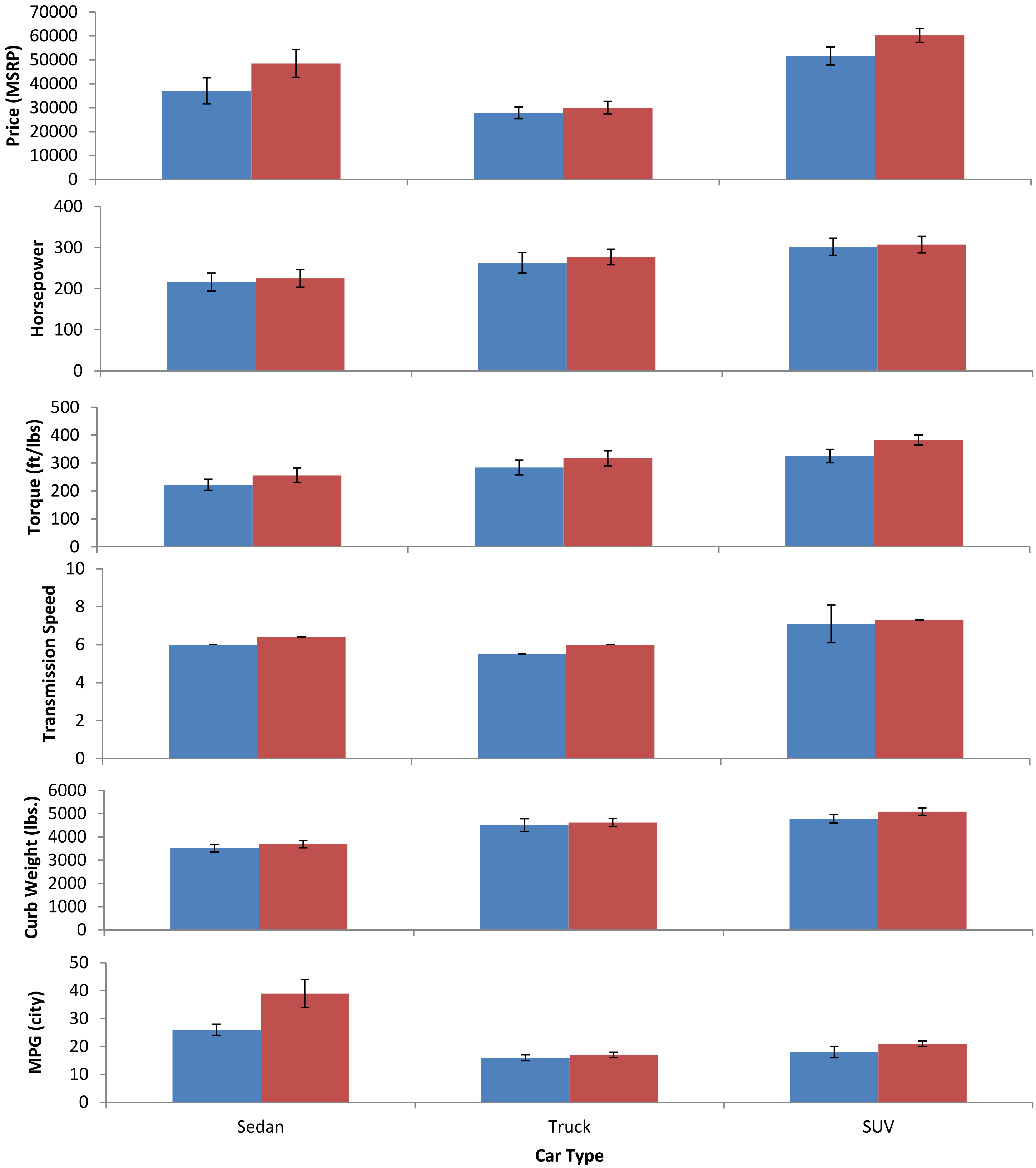

Figure 3: Histogram shows the comparison between base (blue) to green-technology (red) models within car type across variable car components, including price (MSRP), horsepower, torque (feet per pounds), transmission speed, curb weight (pounds) and miles per gallon (MPG) city.

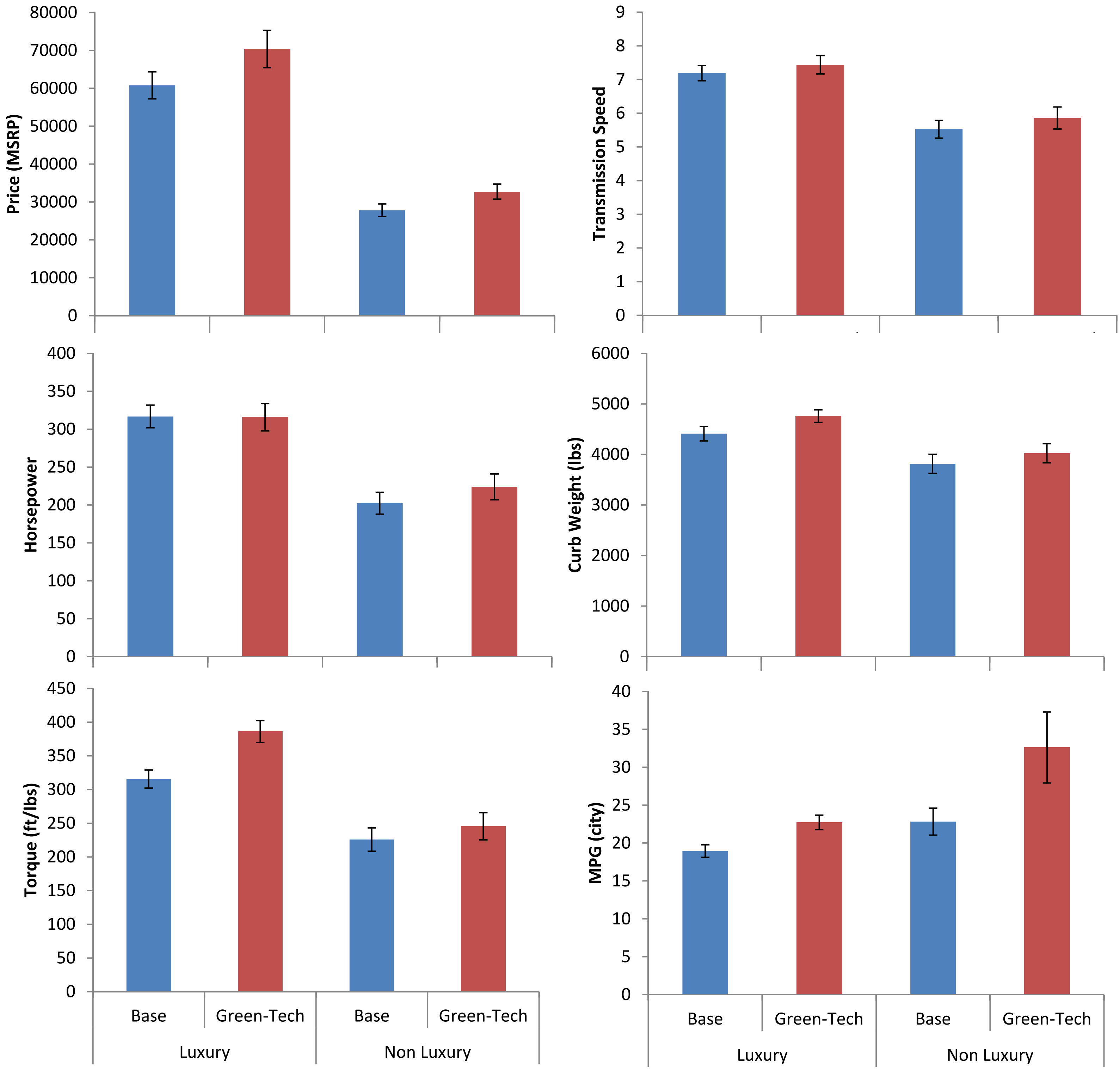

Figure 4: Histogram shows the comparison between base (blue) to green-technology (red) models within luxury or non-luxury vehicles across variable car components, including price (MSRP), horsepower, torque (feet per pounds), transmission speed, curb weight (pounds) and miles per gallon (MPG) city.

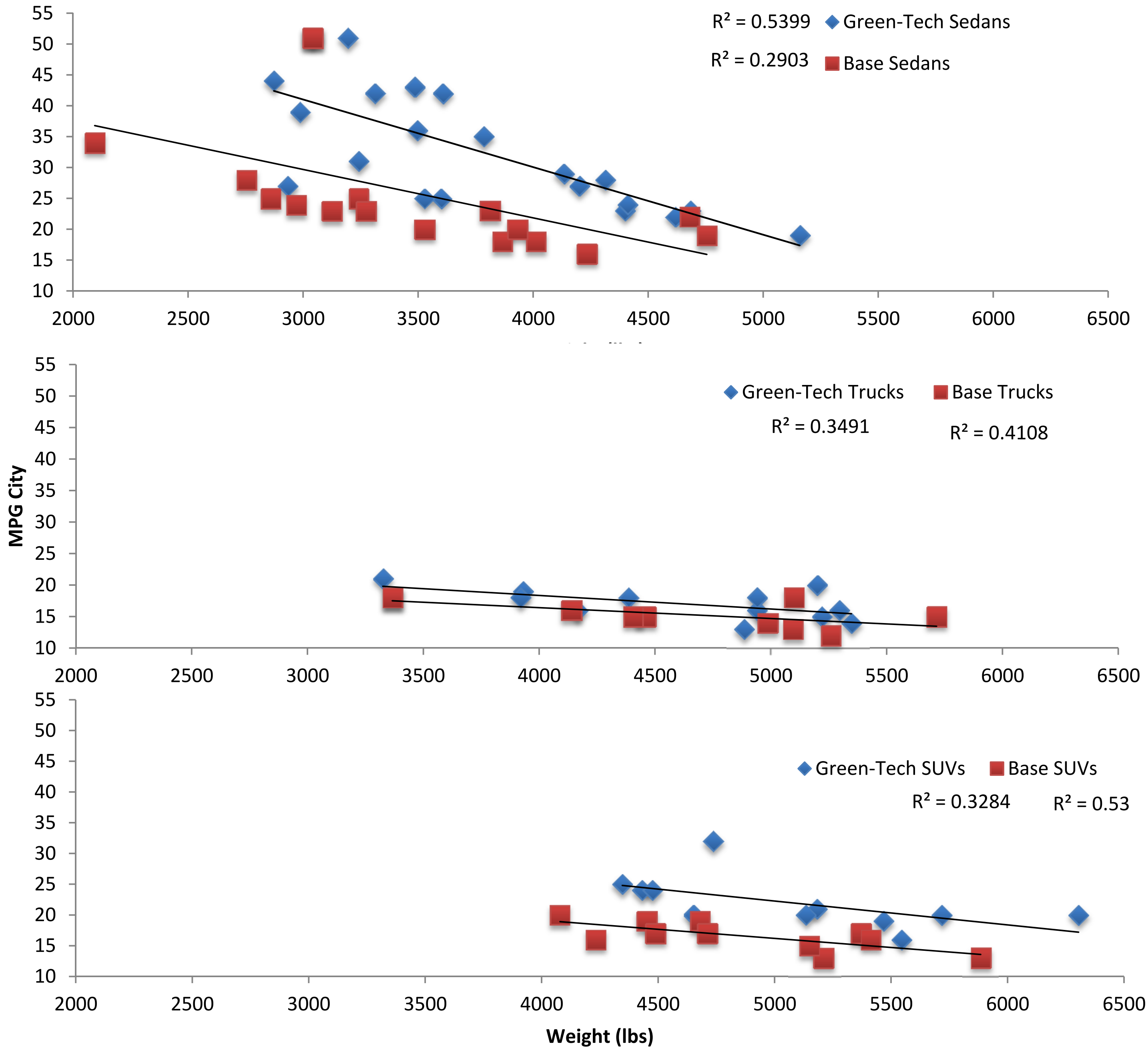

Figure 5: The relationship between miles per gallon (MPG) city and curb weight (pounds) to show the difference in fuel efficiency of base models (red) to green-technology (blue) across sedans (top), trucks (middle), and SUVs (bottom).

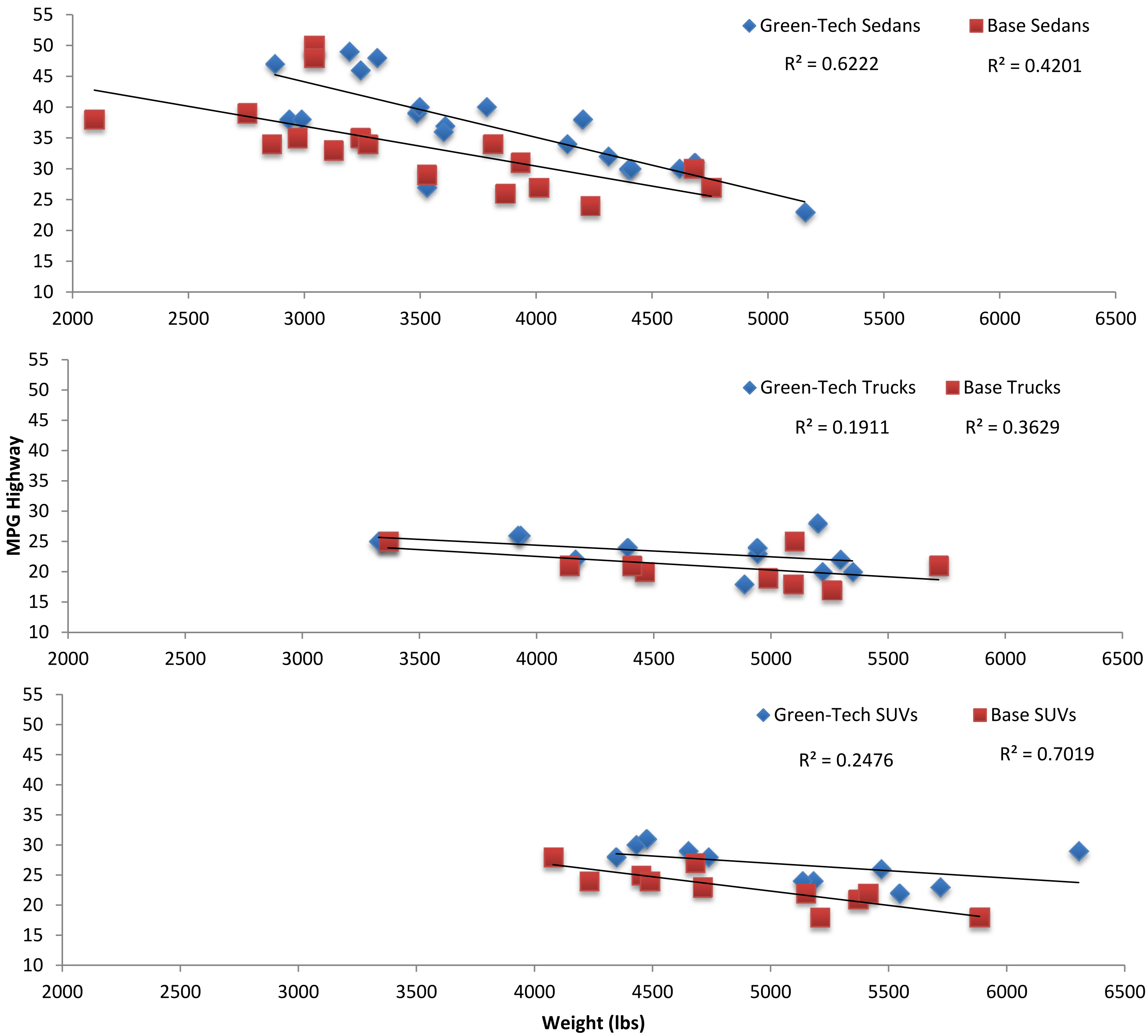

Figure 6: The relationship between miles per gallon (MPG) highway and curb weight (pounds) to show the difference in fuel efficiency of base models (red) to green-technology (blue) across sedans (top), trucks (middle), and SUVs (bottom).

Table 1: Summary statistics of specifications between all vehicles, comparing both base and green-technology models using price (MSRP), horsepower, torque (pounds per feet), transmission speed, curb weight (pounds), miles per gallon (city), and miles per gallon (highway) as variables for comparison.

	Price (MSRP)		Horse Power		Torque (ft/lbs)		Transmission Speed	
	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech
N	47	47	47	47	47	47	37	37
Mean	40728.78	47463.98	247.20	259.87	260.93	300.57	6.24	6.54
Std. Dev.	19880.16	24011.91	90.69	95.68	90.58	116.06	1.36	1.54
S.E.	2931.17	3540.36	13.37	14.11	13.36	17.11	0.22	0.25

	Curb Weight (lbs)		MPG (City)		MPG (Hwy)	
	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech
N	47	47	47	47	47	47
Mean	4048.80	4312.33	21.30	28.74	27.54	33.09
Std. Dev.	909.88	917.50	7.83	19.99	7.72	14.14
S.E.	134.15	135.28	1.16	2.95	1.14	2.09

Table 2: Comparison to show the change (Δ) between base and green-technology models using all vehicles within the study.

Δ Price (MSRP)	Δ Horse Power	Δ Torque (ft/lbs)	Δ Trans. Speed	Δ Curb Weight (lbs)	Δ MPG (city)	Δ MPG (hwy)
6735.20	12.67	39.63	0.30	263.52	7.43	5.55

Table 3: Output of a paired two sample t-test for means to compare base models to their green-technology counterparts of all vehicles across all variable components (price, horsepower, torque, transmission speed, curb weight, miles per gallon city and highway).

	Price (MSRP)	Horse Power	Torque (ft/lbs)	Transmission Speed	Curb Weight (lbs)	MPG (City)	MPG (Hwy)
T-stat	-5.18	-1.36	-3.59	-1.51	-4.49	-3.01	-3.16
P-Value	0.000	0.182	0.001	0.140	0.001	0.004	0.002

Table 4: Summary statistics of specifications between vehicles within car types, comparing both base and green-technology models using price (MSRP), horsepower, torque (pounds per feet), transmission speed, curb weight (pounds), miles per gallon (city), and miles per gallon (highway) as variables for comparison.

Car Type	N		Price (MSRP)		HorsePower		Torque (ft/lbs)		Transmission Speed	
	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech
Sedan	17	24	37080±5462	48558±5874	216±22	225±21	222±20	256±26	6.0±0	6.4±0
Truck	10	10	27879±2486	30025±2620	263±25	277±19	284±26	317±27	5.5±0	6.0±0
SUV	10	14	53722±4902	60280±2963	302±21	307±20	325±24	382±18	7.1±1	7.3±0

Car Type	N		Curb Weight (lbs)		MPG (city)		MPG (highway)	
	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech
Sedan	17	24	3514±160	3688±155	26±2	39±5	34±2	41±3
Truck	10	10	4504±277	4609±176	16±1	17±1	22±1	23±1
SUV	10	14	4784±188	5082±153	18±2	21±1	23±1	27±1

Table 5: Comparison to show the change (Δ) between base and green-technology models within car types (sedan, truck and SUV).

Car Type	Δ Price (MSRP)	Δ HorsePower	Δ Torque (ft/lbs)	Δ Trans. Speed	Δ Curb Weight (lbs)	Δ MPG (city)	Δ MPG (highway)
Sedan	11478	9	34	0.4	173	13	7
Truck	2146	14	33	0.5	105	0.4	0.9
SUV	8621	5	57	0.2	299	3	3

Table 6: Output of a one-way anova (F-value and Significance) to compare base models to their green-technology counterparts within car type across all variable components (price, horsepower, torque, transmission speed, curb weight, miles per gallon city and highway).

	Price (MSRP)	Horse Power	Torque (ft/lbs)	Transmission Speed	Curb Weight (lbs)	MPG (City)	MPG (Highway)
F-value	0.801	0.169	2.415	n/a	0.536	2.585	1.212
Significance	0.445	0.845	0.102	n/a	0.589	0.087	0.307

Table 7: Summary statistics of specifications between vehicles within luxury models, comparing both base and green-technology models using price (MSRP), horsepower, torque (pounds per feet), transmission speed, curb weight (pounds), miles per gallon (city), and miles per gallon (highway) as variables for comparison.

ONLY Lux.		Price (MSRP)		Horse Power		Torque (ft/lbs)		Powertrain (Speeds)	
		Base	Green-Tech	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech
	N	19	19	19	19	19	19	16	16
	Mean	60781	70361	317	316	316	386	7	7
	Std. Dev.	15122.88	20958.05	63.22	76.54	56.57	69.14	0.91	1.09
	S.E.	3564.50	4939.86	14.90	18.04	13.33	16.30	0.23	0.27
ONLY Lux.		Curb Weight (lbs)		City		Highway			
		Base	Green-Tech	Base	Green-Tech	Base	Green-Tech		
	N	19	19	19	19	19	19		
	Mean	4412	4759	19	23	26	28		
	Std. Dev.	612.99	533.31	3.51	4.08	3.74	3.43		
	S.E.	144.48	125.70	0.83	0.96	0.88	0.81		

Table 8: Comparison to show the change (Δ) between base and green-technology models within luxury models.

Δ Price (MSRP)	Δ Horse Power	Δ Torque (ft/lbs)	Δ Transmission Speed	Δ Curb Weight (lbs)	Δ MPG (City)	Δ MPG (Highway)
9580	-1	71	0	347	4	2

Table 9: Summary statistics of specifications between all vehicles within non-luxury models, comparing both base and green-technology models using price (MSRP), horsepower, torque (pounds per feet), transmission speed, curb weight (pounds), miles per gallon (city), and miles per gallon (highway) as variables for comparison.

NON Lux.		Price (MSRP)		Horse Power		Torque (ft/lbs)		Transmission Speed	
		Base	Green-Tech	Base	Green-Tech	Base	Green-Tech	Base	Green-Tech
	N	28	28	28	28	28	28	21	21
	Mean	27,838	32,744	202	224	226	246	6	6
	Std. Dev.	8619.79	10496.35	76.62	90.24	91.58	106.85	1.21	1.49
	S.E.	1628.99	1983.62	14.48	17.05	17.31	20.19	0.26	0.33
NON Lux.		Curb Weight (lbs)		MPG (City)		MPG (Highway)			
		Base	Green-Tech	Base	Green-Tech	Base	Green-Tech		
	N	28	28	28	28	28	28		
	Mean	3,815	4,025	23	33	29	36		
	Std. Dev.	999.39	1002.54	9.40	24.82	8.77	17.37		
	S.E.	188.87	189.46	1.78	4.69	1.66	3.28		

Table 10: Comparison to show the change (Δ) between base and green-technology models within luxury models.

Δ Price (MSRP)	Δ Horse Power	Δ Torque (ft/lbs)	Δ Transmission Speed	Δ Curb Weight (lbs)	Δ MPG (City)	Δ MPG (Highway)
4,906	22	20	0	210	10	7

Table 11: Output of a one-way anova (F-value and Significance) to compare base models to their green-technology counterparts within luxury/non-luxury vehicles across all variable components (price, horsepower, torque, transmission speed, curb weight, miles per gallon city and highway).

	Price (MSRP)	Horse Power	Torque (ft/lbs)	Transmission Speed	Curb Weight (lbs)	MPG (City)	MPG (Hwy)
F-value	2.539	0.412	6.42	n/a	0.87	1.628	2.605
Sig. value	0.118	0.524	0.015	n/a	0.356	0.209	0.113

Table 12: Modern innovations used in this study to categorize vehicles as green-technology models with a description of how the technology benefits the automobile.

Innovation:	**Description:**
Automated Manual Transmission (AMT) Continuously Variable Transmission (CVT)	Both take power from the engine and create a ratio of power output to the wheels. AMT's use gears to create the ratio. The more gears present, the more efficient the engine can preform. CVT's use a pulley system that can create infinite gear ratios, resulting in better efficiency
Electric Operation	Uses rechargeable batteries to power electric motors that are connected to the wheels. Full horsepower and torque is available at any speed. Zero gas and Zero polluting emissions.
Hybrid	Uses electric motor and a gasoline engine. Both work together to create combined power. Low speed/low demand tasks use electric power to conserve gas. High demand tasks requires concurrent operation of both gas and electric motors
Forced Induction (turbocharging & supercharging)	Turbocharging uses spent exhaust gases to drive an induction turbine that forces more oxygen into the cylinders. Supercharging creates power similarly, but uses the engine belt to drive the induction turbine, instead of exhaust gasses. Increases efficiency and power, while reducing engine size and fuel consumption.
Weight saving materials	Materials like aluminum and composite materials help reduce overall vehicle weight. This reduces engine effort for it is moving less weight.
Variable Valve Timing (VVT)	The process where intake and exhaust valves open to allow oxygen and exhaust gasses to enter and leave the cylinder during the induction and exhaust stokes.
Direct Injection (DI)	Injects gasoline, as a mist, directly into the combustion chamber (cylinder), allowing for a complete burn and detonation of the gasoline in the compression and power stroke, resulting in more power and efficiency.
Cylinder Deactivation	Fuel is shut off to certain cylinders under low rpm conditions where power is not needed for operation.
Start-Stop system	Shuts engine off while at a full stop. Restarts engine once brake pedal is released. Prevents unnecessary fuel burning
Diesel Fuel	Contains more energy per unit volume allowing it to have significant efficiency advantages over gasoline. Roughly 30-35% more efficient.