Efficiency Alone as a Solution to Increasing Energy Consumption

By

Luke Haidorfer

Submitted to the Department of Mechanical
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Signature of Author..
Department of Mechanical Engineering
May 6, 2005

Certified by ....
Timothy G. Gutowski
Associate Department Head
Professor of Mechanical Engineering
Director, Laboratory for Manufacturing and Productivity

Accepted by ....
Ernest E. Cravalo
Van Buren N. Hansford Faculty Fellow
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee

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ABSTRACT

A statistical analysis was performed to determine the effect of efficiency on the total US energy consumption of automobiles and refrigerators. Review of literature shows that there are many different opinions regarding this issue. Trends in energy consumption were constructed using historical data from government agencies and prior studies on energy efficiency. The discussion includes a range of topics that help to understand what factors influence changes in energy consumption the most. It was found that increasing efficiency was not able to reduce motor fuel consumption for automobiles, but was successful in decreasing electricity consumption for refrigerators.

Thesis supervisor: Timothy Gutowski
Title: Associate Department Head, Professor of Mechanical Engineering, Director, Laboratory for Manufacturing and Productivity, Thesis Supervisor

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Table of Contents

Introduction 6

A Short Background: Three Perspectives 7

Amory Lovins and the Technology Optimists 7

Wackernagel and Rees and the Natural Capitalists 8

Khazoom, Brookes and the Economists 9

Data 10

Passenger Cars 10

Refrigerators 13

Discussion 17

The US Transportation Sector and Electricity Generation 17

Automobile vs. Refrigerator User Behavior 18

National Growth Analysis 20

Phenomenon Seen During Price Shocks 24

Long Term Rebound Effect 25

Effective Efficiency Regulation 26

Conclusion 29

References 31

List of Figures

Figure 1: Fuel Consumption by Automobiles in the US (1936-2000) 10
Figure 2: Miles per capita (1950-1999).. 11
Figure 3: The CAFE standards and fuel efficiencies (1974-2000) 12
Figure 4: Gasoline Prices and Taxes (1949-2002) 13
Figure 5: Total Electricity Used by Refrigerators in the US (1982-1996) 14
Figure 6: Number of Households vs. Number of Refrigerators (1982-1997) 15
Figure 7: Number of Refrigerators in Operation (1982-1995) 15
Figure 8: Efficiency of New Refrigerators (1947-1996) 17
Figure 9: Means of Transportation to Work (1985-2003) 19
Figure 10: Distance to Work 20
Figure 11: Gasoline Consumed, Population, Miles per Capita, and Vehicle Fuel Efficiency (1950-1999) 21
Figure 12: Electricity Use, Refrigerators in Operation, and Inverse Efficiency (1982-1995) 22
Figure 13: Change in Efficiency vs. Change is Population and Change in Miles per Capita for Automobiles (1950-1998) 23
Figure 14: Change in Efficiency vs. Change in Refrigerators in Operation (1982-1995) 24
Figure 15: Price Shock Years 25
Figure 16: Efficiency vs. Miles per Capita (1950-1999) 26
Figure 17: Gasoline Tax and Gasoline Expenditures (1950-2000) 28

Introduction

It can be argued that humanity today is on an unsustainable path. Richard Smalley, a Nobel Prize winner in 1996 for his work in chemistry, who makes speeches to congress on sustainable low-emission electricity generation, believes that energy is currently the most pressing worldwide issue (Smalley 2004). It is estimated that in 2003 the world used 12 terawatts of power, 3.3 of which were used in the US (Ghoniem 2005). Considering the steady growth of world population and the growth of developing economies like China, there are no apparent signs of a letup of use of power. The question of how to reduce energy consumption, or to merely keep it level, remains unanswered. This thesis attempts to explain why there is still no simple solution. Reduced consumption of energy is not always a result of increased efficiency

The body of the paper is broken down into three major sections: background, data, and discussion. The first section deals with what different groups of people, technology optimists, natural capitalists, and economists, think about the issue of energy efficiency. The range of their opinions on the usefulness of energy efficiency is large. The data section presents data for fuel and electricity use, how those estimates are broken down, and any assumptions that were made. The discussion section presents the data in new ways, highlighting factors that are most closely correlated to fuel or electricity consumption. The discussion also touches upon other related factors that, for example, can influence how much the average American drives each year. These tangents illustrate the complexity of the problem, further suggesting that efficiency is not the only piece in the puzzle.

Choosing to look at automobiles and refrigerators is appropriate because they are both huge consumers of energy. They are also different in many ways. The difference will become apparent as evidence shows that for one of the consumer items, improving efficiency has actually been the reduced energy consumed. The larger question pertains to whether the success of some products can be translated to others. The approach of this study should allow people from any background to acquire a basic understanding of what is going on in the world of energy efficiency and consumption.

A Short Background: Three Perspectives

There is a wealth of material published on efficiency and whether or not it will result in conservation. The earliest relevant work goes back to 1865, Stanley Jevons' *The Coal Question*, in which increasing coal production is directly linked to improvements in the technology used to make it. Since then, there have been three major camps: environmentalists, economic ecologists, and economists. Horrace Herring and Vaclav Smil have done an excellent job being objective and telling the story of these three groups without distorting information. Both Herring and Smil believe that energy efficiency is part of the solution to the problem, but not the simple answer. To date no one has a perfect solution, and likely a combination of actions will prove to have the greatest impact, efficiency and regulation being two major contributors. In the end, however, as many would agree, society will have to change its attitude towards energy. Herring and Smil's efforts to inform the public about the debate is a step in the right direction. The three viewpoints following are hotly debated, but they should allow the reader to see what the major trains of thought are. This section will provide the background for the data and discussion sections in which hopefully new insight can be revealed.

Amory Lovins and the Technology Optimists

Amory Lovins of the Rocky Mountain Institute (RMI) has been labeled as the most "enthusiastic practitioner" of higher energy conversion efficiency. Lovins believes that not only are his organizations efficiency ideas energy saving, but also cost-effective and even profitable in some cases. Many skeptics, however, believe that the predictions coming out of the RMI, such as claiming that the US can potentially reduce its energy demand by 75% in the foreseeable future, are too optimistic (Smil 2003). One specific example of an arguably over optimistic prediction is for the conversion efficiency of electric motors. Currently, some of the most efficient electric motors have efficiencies on the order of 95% (DOE 2004). In spite of this, the RMI thinks that it can achieve a 50% increase in the efficiency of electric motors (RMI 2004). Lovins also believes in the "Hypercar", an ultra-efficient hydrogen powered vehicle that will take the automobile market by storm and radically change the fuel demands of the transportation sector in the next generation (Lovins 2004).

Mr. Lovins, who I have deemed an appropriate representative of the technology optimist group, is responsible for many ideas which lead society to think about energy consumption, no doubt a great contribution. His vision maintains that a future shift towards a more service-based and dematerialized economy can lead to reductions in energy use without a sacrifice in quality of life. Perhaps Lovins can not be considered a pure "technology optimist" because he is also a firm believer in the concept of natural capital (Smil 2003).

Wackernagel and Rees and the Natural Capitalists

In their description of natural capital Mathis Wackernagel and William Reese claim, "Ecological economists acknowledge that industrialized societies depend for survival not only on labor and human-made capital, but also on natural capital." The concept of natural capital is similar to the idea that some commodities and natural resources are part of the essential first steps in the manufacturing process. The difference is that current prices, crude oil for example, hardly represent the fact that there is a limited world wide supply. Prices respond to supply and demand, and the absence of supply in the presence of demand does not necessarily mean that market senses depletion, rather a mere slowing of production. Ecological economists recognize that there are two forms of natural capital: renewable and non-renewable. Renewable natural capital comprises of biological and replenishable assets such as biomass, water, and solar energy. Excellent examples of non-renewable natural capital, on the other hand, are crude oil, minerals, and ores whose depletions are more permanent if their uses are not compensated for. Natural capitalists believe in maintaining a, "stock of natural assets that is capable of producing a sustainable flow." They believe in the ecosphere providing "biophysical resources and waste sinks" which can recover from a limited amount of environmental damage caused by human activity. The human economy has to take into account that consumption of natural capital per capita has to drop if the population increases because the world's pool of resources is basically going to remain constant. Prices in a natural capitalist system supposedly take into account both the environmental and market driven costs associated with obtaining a resource (Wackernagel and Reese 1997).

This concept is reflected in the fact that some people would argue that taxes on fossil fuels today do not adequately represent the environmental damages that using those fuels entails. The third group, hard line economists included, has a totally different mentality on the consumption issue. They seem to understand what drives consumption better than anyone.

Khazoom, Brookes and the Economists

Economists would argue that market forces alone are a sufficient regulator of people's consuming tendencies and the entrance of environmentally friendly technologies into the market place. This goes along with Adam Smith's invisible hand theory. When the supply of crude oil reserve gets low enough and the cost of pollution are both reflected by the price, people will naturally turn to then more competitive alternative sources of energy and effectively change their polluting ways without sacrificing profit.

Khazoom and Brookes have devised a postulate which predicts the long run macroeconomic effects of rising productivity and efficiency. An interesting example of this theory in action can be found in Herring's paper, regarding the air travel industry. It was thought that making larger planes with a higher seating capacity would reduce the number of flights, however, when ticket price fell due to the expansion more people were encouraged to fly. The net result is that more planes were needed to meet the new customer demand. In this regard, economists are strong believers in the rebound effect which says that more efficient cars would encourage people to drive more because their gas costs would be cheaper per mile. Economists are skeptical of benefits of efficiency because "overzealous pursuit of energy efficiency per se would damage the economy through misallocation of resources," and the economic costs would outweigh the potential savings (Herring 1998).

Economists understand this trade off well as relating to "open-access". In 1968, Ecologist Garrett Hardin wrote *Tragedy of the Commons*, a story used to illustrate "open-access", the macroeconomic effects of making decisions on the microeconomic level. In an ancient community of a large group of farmers the individual has to be aware of his own needs and the needs of the community at large. On the micro scale, if each farmer attempts to maximize their individual yields, the entire farm may not be able to support the group as a whole and ecological disaster may result. On the other hand, if each farmer makes decisions based on the interests of the entire farm and seeks to maximize their profit within that framework, sustainability of the entire farm will allow for long and potentially prosperous farming careers. This story is actually one that a natural capitalist uses to show the need for balancing economic success with environmental consideration, but one can see where some of these leading theories, namely economic and natural capital, converge (De Young 1999).

Data

Passenger Cars

Fuel consumption for automobiles is defined by the amount of motor fuel consumed in the US every year, and is the product of the total miles traveled in the US and the overall automobile fleet efficiency for each of those years. Figure 1 shows calculated nation wide fuel consumption values steadily increasing throughout the years. The only instances of decreasing yearly impact are during price shocks or major world events.

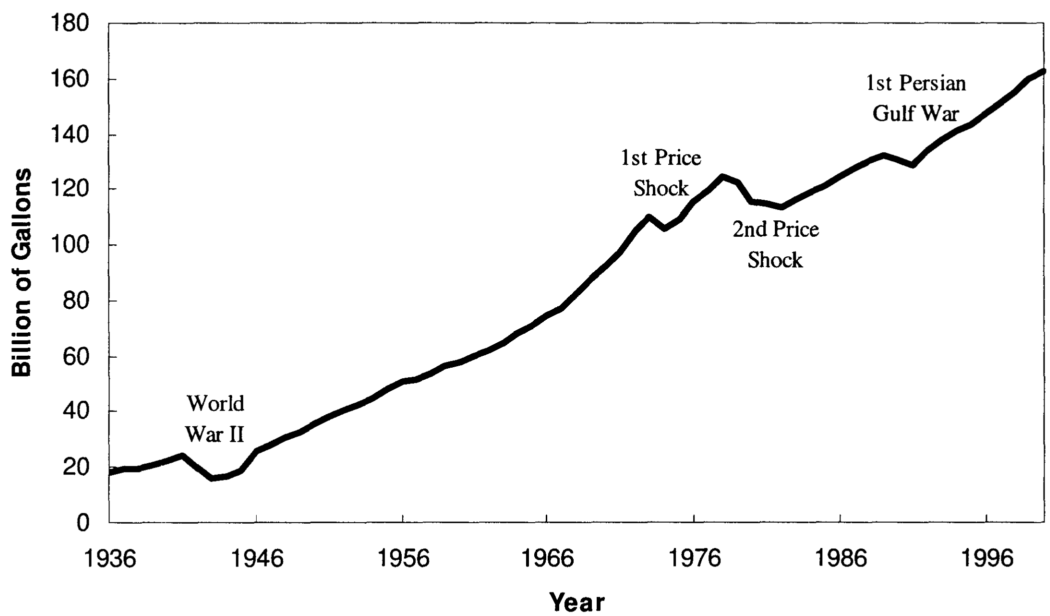

Figure 1: Fuel Consumption by Automobiles in the US (1936-2000). Calculated aggregate values show that increasing US fuel consumption is interrupted only by major price shocks and world events (BC 1997a, BC 1997b, DOT 2003a, DOT 2003b).

Miles per capita is the total number of miles driven by Americans each year divided by the population. The calculations presented in figure 2 show steady yearly increases.

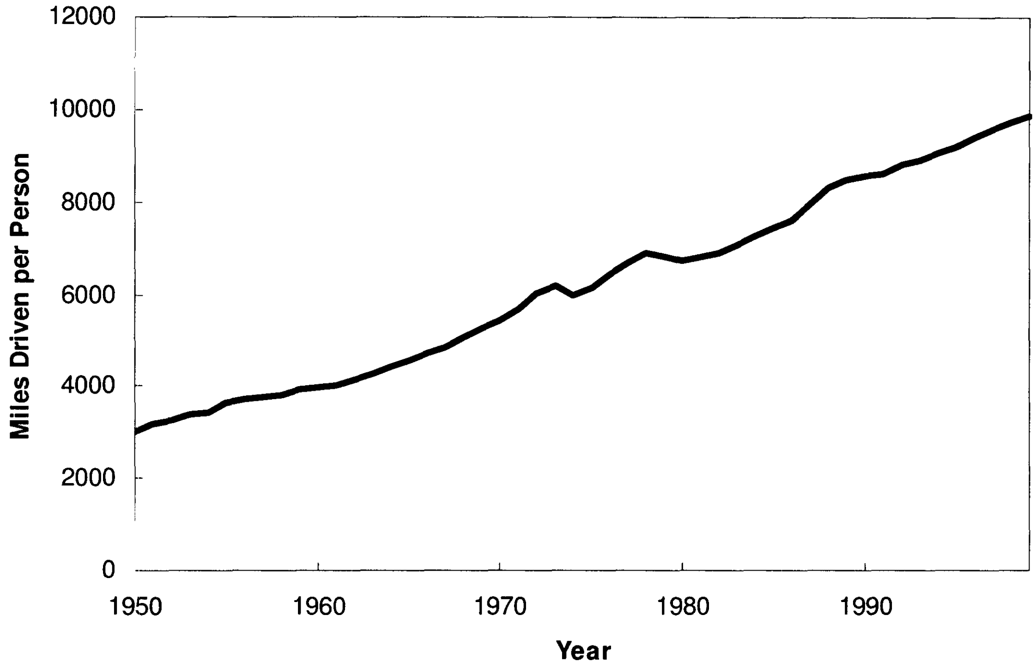

Figure 2: Miles per capita (1950-1999). The calculated average number of miles driven per person each year in the US has increased steadily over the forty-nine year period shown (BC 1997b, CB 2000, DOT 2003a).

Regulations on fuel consumption include "direct" and "indirect regulations". Figure 3 represents a direct regulation, called the Corporate Average Fuel Economy (CAFE) standards, in which vehicle efficiency is being regulated. In this case, the standard measure of efficiency is miles per gallon, or how far a car can travel on one gallon of gas. The figure shows a phase-in period following when the standards were first enforced by the federal government in 1978, and the eventual convergence of regulation efficiency values and actual overall fleet values. In the graph light trucks (Lt. Trk.) represent vehicles such as SUV's, vans, and pickup trucks. The standards only apply to new vehicles.

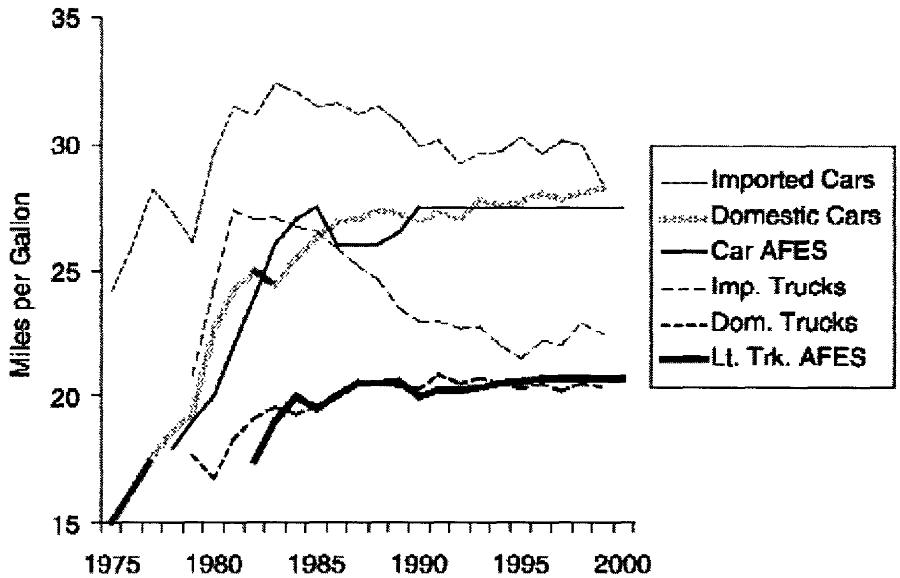

Figure 3: The CAFE standards and fuel efficiencies (1974-2000). This graph, taken from page 14 of NRC 2002, illustrates the standards set for both cars and light trucks from 1978 through 2000. Light tuck standards came into effect a little while after the car standards. AFES stands for average fuel economy standards. It is interesting to note that both imported and domestic vehicles adjusted their production to incorporate technologies that more closely match the standards.

One example of an "indirect regulation" is a tax imposed on the fuel used to power vehicles. Tax is incorporated into the final price of gasoline. The other costs that contribute to the total price include the market price of crude and the price of transporting and distributing the fuel. Figure 4 shows the annual tax and the retail price of gasoline in cents per gallon. In 1973, the national speed limit was set to 55 miles per hour, and in the early 1970's, the phase-out of leaded gasoline was initiated by the federal government. Switching to unleaded fuel originally caused the cost of refining to increase 2.4 cents per gallon. Considering inflation, however, real prices were lower in 1999, for example, than they were in 1949.

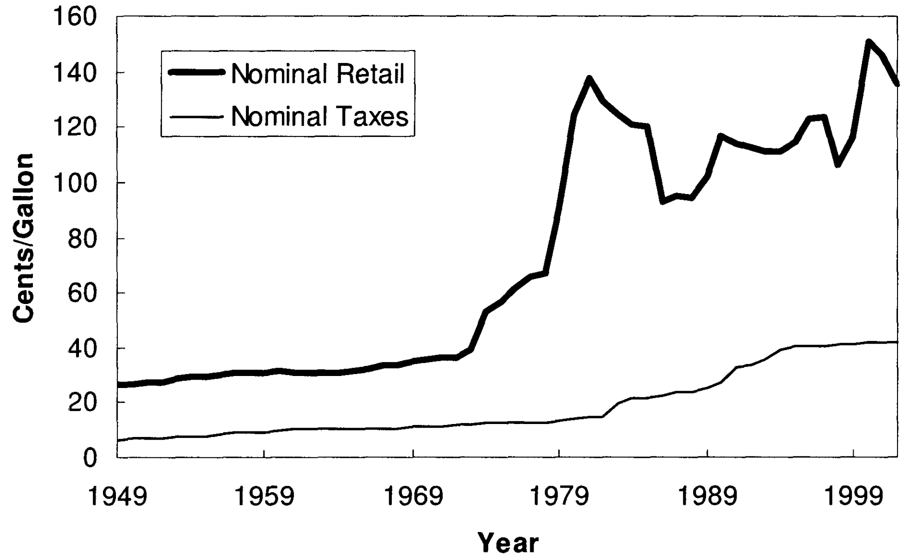

Figure 4: Gasoline Prices and Taxes (1949-2002). Despite fluctuating retail prices, taxes have been known to rise steadily throughout the years (API 2003, EIA 2003).

Refrigerators

The energy use in billions of kWh for refrigerators, figure 5, is estimated by taking the product of the number of refrigerators in operation in the US and the efficiency of the average refrigerator in operation for each year.

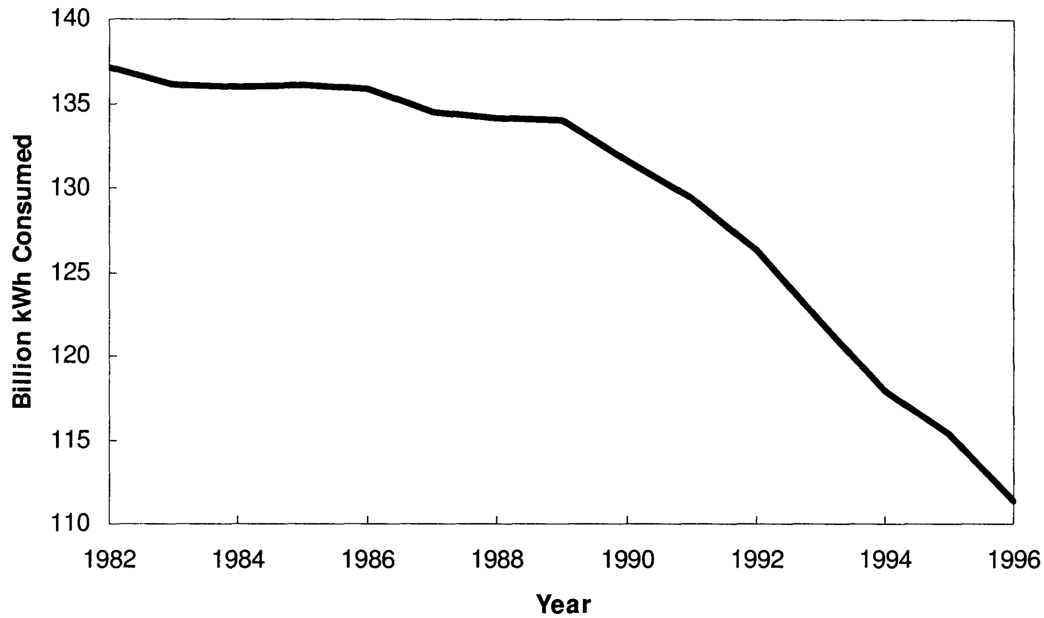

Figure 5: Total Electricity Used by Refrigerators in the US (1982-1996). Estimated values show that the amount of energy that refrigerators in the US are consuming every year has decreased since 1982 (Battles 2005, CB 2003, EIA 1993, EIA 1997, Rosenfeld 1999).

The number of refrigerators in operation, figure 7, can be estimated knowing the number of households in the US, and the formula that fits data from the Energy Information Administration's 1982 to 1997 Residential Energy Consumption Surveys, conducted every two or three years. Within each study is the number of households with one refrigerator and number of households with two or more refrigerators. With this information, the number of refrigerators in operation during any one of the survey years can be estimated. Figure 6 shows the estimated number of refrigerators and the number of households in America during survey years for 1982 through 1997.

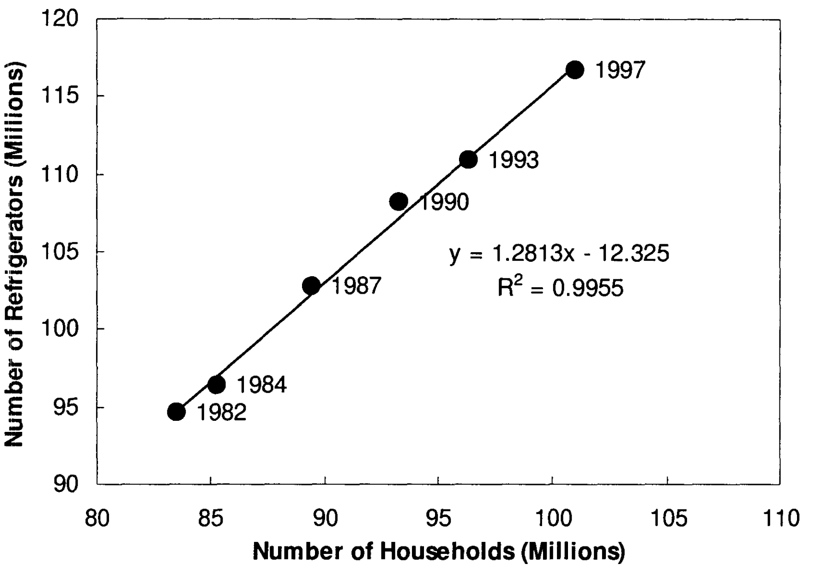

Figure 6: Number of Households vs. Number of Refrigerators (1982-1997). The linear trend line allows for an estimate of the number of refrigerators in operation for any year in between 1982 and 1997 (Battles 2005, CB 2003, EIA 1993, EIA 1997).

For non-survey years, the number of refrigerators in operation can be estimated with the equation of the linear trend line in figure 6. Figure 7 contains the approximate total number of refrigerators in operation each year.

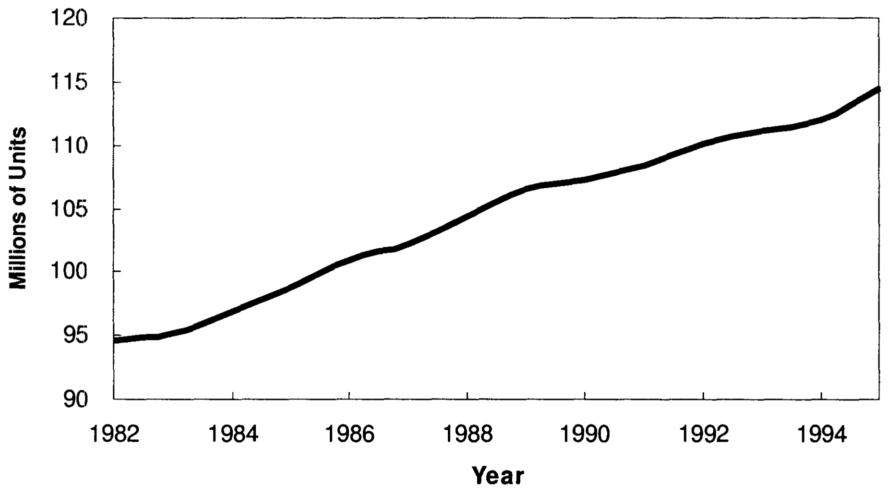

Figure 7: Number of Refrigerators in Operation (1982-1995). The estimate for number of refrigerators in operation shows steady increase in between 1982 and 1995 (Battles 2005, CB 2003, EIA 1993, EIA 1997).

Yearly average efficiency estimates for the refrigerators in operation are found with data on new refrigerator efficiencies and a distribution of the age of refrigerators in operation in the US. The EIA 1993 and 1997 studies have a refrigerator age distribution for household in the US, and the Rosenberg study has new refrigerator efficiencies. Equation 1 shows how the yearly average efficiency of refrigerators in operation is estimated. In this approximation it is assumed that the refrigerators keep their original efficiency regardless of age, that the ownership age distribution remains constant based on the 1993 and 1997 studies, and that the refrigerators in operation are kept running all of the time.

$$E(y) = (H_{<2} + C_{<2})*Average[E_{new}(y:y-1)] + (H_{2-4} + C_{2-4})*Average[E_{new}(y-2:y-4)] + (H_{5-9} + C_{5-9})*Average[E_{new}(y-5:y-9)] + (H_{10-19} + C_{10-19})*Average[E_{new}(y-10:y-19)] + (H_{>20} + C_{>20})*Average[E_{new}(y-20:y-25)] \quad (1)$$

Variables:
E = Average efficiency of refrigerators in use
y = year in question
$H_{<2}$ = % of households with refrigerators that are less than 2 years old
H_{2-4} = " " 2 to 4 years old
H_{5-9} = " " 5 to 9 years old
H_{10-19} = " " 10 to 19 years old
$H_{>20}$ = " " greater that 20 years old
C_{XXX} = correction factor for the % of people who did not know how old their refrigerators were
E_{new} = Average efficiency of refrigerators being produced in year y

Refrigerators made in 1996 are dramatically more efficient than those manufactured in 1974, figure 8. Before 1974 refrigerators used less energy possibly due to the fact that they had smaller volumes on average, but there are a host of other possible reasons as well, refrigerators before 1974 could have also used better or more insulation for example. All of the California and Federal Standards were met by manufacturers.

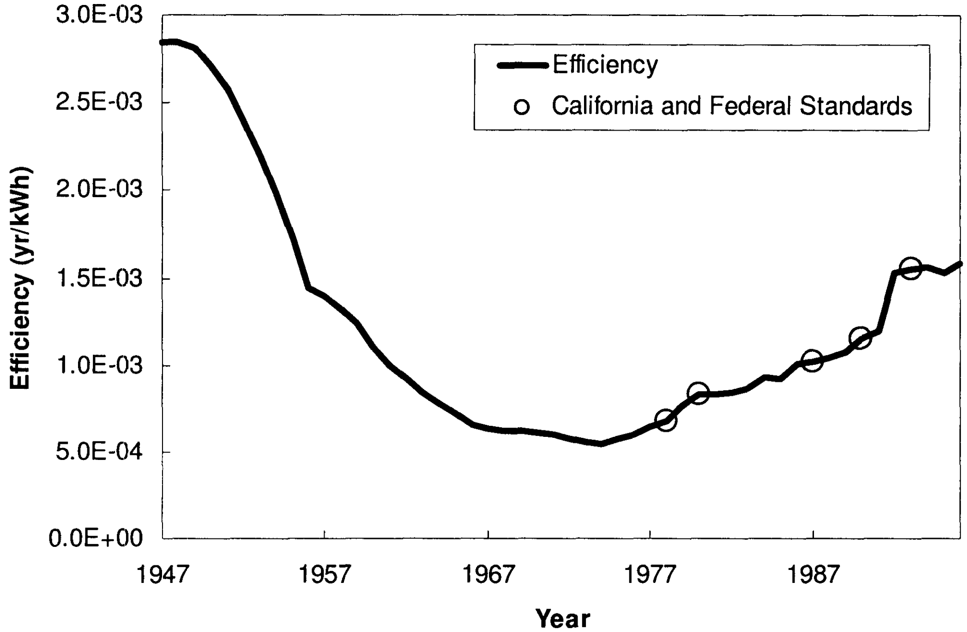

Figure 8: Efficiency of New Refrigerators (1947-1996). Efficiency of new refrigerators has increased from its low in 1974 (Rosenfeld 1999).

Discussion

The US Transportation Sector and Electricity Generation

The transportation sector is responsible for the consumption of 70 percent of the oil that the US consumes. Due to recent consumption growth in this sector, mainly due to increasing consumption by light trucks, over half of the oil needed to run America's vehicle fleet, in addition to all of the other oil intensive products or structures in the US, is imported (EIA 2005). This creates a supply problem, and forces dependence on oil production in OPEC and other crude exporting countries. Due to the political instability of these places, the US is vulnerable to price shock.

Electricity generation is quite a different story because the primary source of fuel that is used for generation is coal, a domestically abundant resource. America's supply of coal is far more stable that that of gasoline. Unfortunately, it is a very dirty fuel that also does not allow for smaller generation units because of the sheer quantity of coal needed to produce significant power. These characteristics limit the applicability of coal power and force continued dependence on oil and natural gas which when used to generate electricity, can ramp up and down power output during peak demand periods. Currently, about 20 percent of the electricity in the US is generated by oil and natural gas plants (EIA 2005). For reference, refrigerators consumed about 13 percent of all of the electricity used in housing units in 1997 (EIA 1997), and the residential sector has been consistently responsible for consuming about 20 percent of all of the electricity in the US (EIA 2005).

Automobile vs. Refrigerator User Behavior

User behavior information is essential for understanding how a product consumes energy. In the case of the refrigerator and the automobile, the two user behaviors are at two ends of the spectrum. While refrigerators consume slightly more electricity when they are opened, in general people run them continuously. As a result, there is no need to present any information in the data section for user behavior for refrigerators.

Automobile fuel consumed is significantly effected by user behavior. While commuters may consistently drive their cars to work, they can also decide to carpool, drive their car to the commuter rail, or in some cases take public transportation all the way to work and use their cars for weekend travel instead. These behavioral scenarios say nothing about how the average commute time has changed due to people moving out to the suburbs, crowding and car ownership in cities, and how people choose to get around during their leisure time. The miles per capita graph in the data section indicate that more miles are being driven by the average American.

According to the Bureau of Transportation Statistics, Minneapolis-St. Paul, Minnesota has the worst case of increased annual person-hours of highway traffic delay per person in America due to increased population and city growth. From the twenty year period from 1982 to 2002 the average annual delay rose 2,100% from a mere one hour in 1982, to eleven hours in 1992, to twenty-two hours in 2002. Twenty-two hours of waiting in traffic is two more hours than the average wait time for people in large urban areas (population one to three million) according to the study. For all of the locations that these numbers were recorded, the average increase was 243%. More hours idling translates into more fuel consumption. Not only are people traveling more, but they are waiting in traffic longer (BTS 2004b).

In another study, the American Housing Survey for the United States: 2003, the US department of housing and urban development showed how people were changing their means of transportation to work, figure 9. Unfortunately, this study shows that less people are finding alternative methods for getting to work. From the years 1985 to 2003 automobiles represented 87 to 88 percent of the way people got to work, and the great majority of those were single riders.

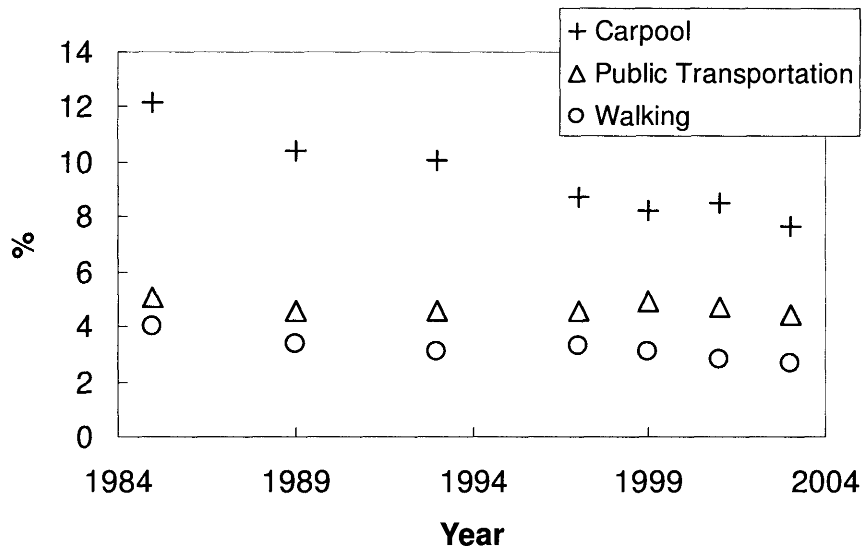

Figure 9: Means of Transportation to Work (1985-2003). Fewer people are resorting to alternative methods of getting to work. Carpooling has declined the most (BTS 2004a).

This phenomenon, however, might be due to the fact that people live farther from work these days. Figure 10 shows this trend for the years 1985 and 2003.

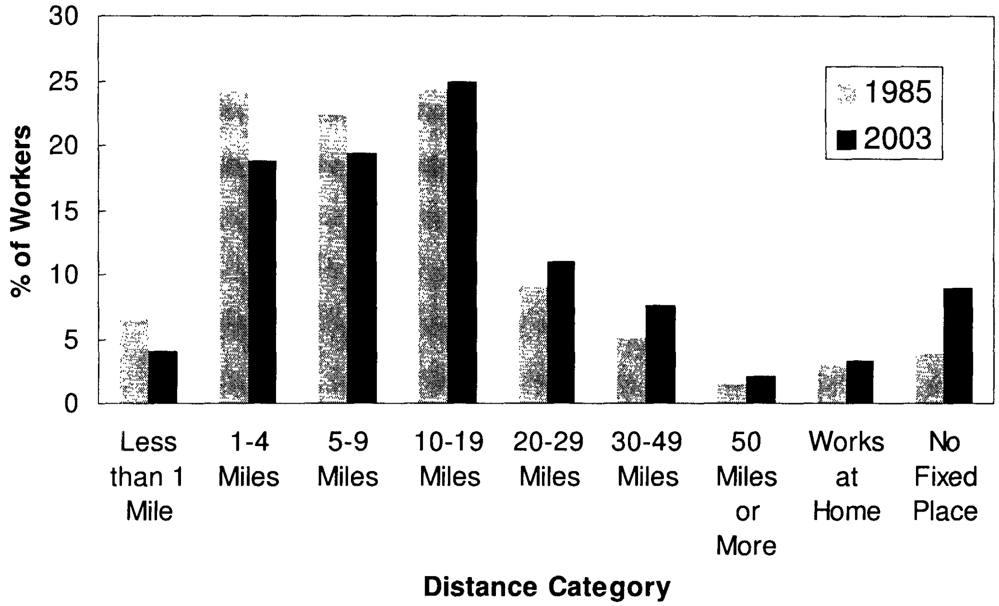

Figure 10: Distance to Work. There is a shift from people living 1 to 9 miles from work in 1985 to 20 to 49 miles from work in 2003 (DHUD 1985, DHUD 2003).

The nature of automobile and refrigerator user behaviors are different, therefore when considering the causes of increasing or decreasing fuel consumption or electricity use, different assumptions have to be made. In the case of refrigerators, user behavior can be considered as constant. On the other hand, for automobiles user behavior is a potential dependent variable that has changed over the years. One interesting relationship between user behavior and efficiency will be discussed later in the subsection entitled rebound effect.

National Growth Analysis

Looking at a slightly different version of the IPAT equation, equation 2, is a simple way of trying to determine the causes of a change in fuel consumed or electricity used. In equation 2, "I" is the impact, in either fuel or energy consumed, "P" is the population or number of households, "M" is miles per capita or average number of refrigerators per household, and "E" represents the efficiency in either miles per gallon or years of operation per kWh.

$$I = PM(1/E) \tag{2}$$

Equation 2 helps determine what the most influential factors are for a change in impact. As seen in the calculated automobile data, figure 11, increasing efficiency does not necessarily always lead to lower consumption.

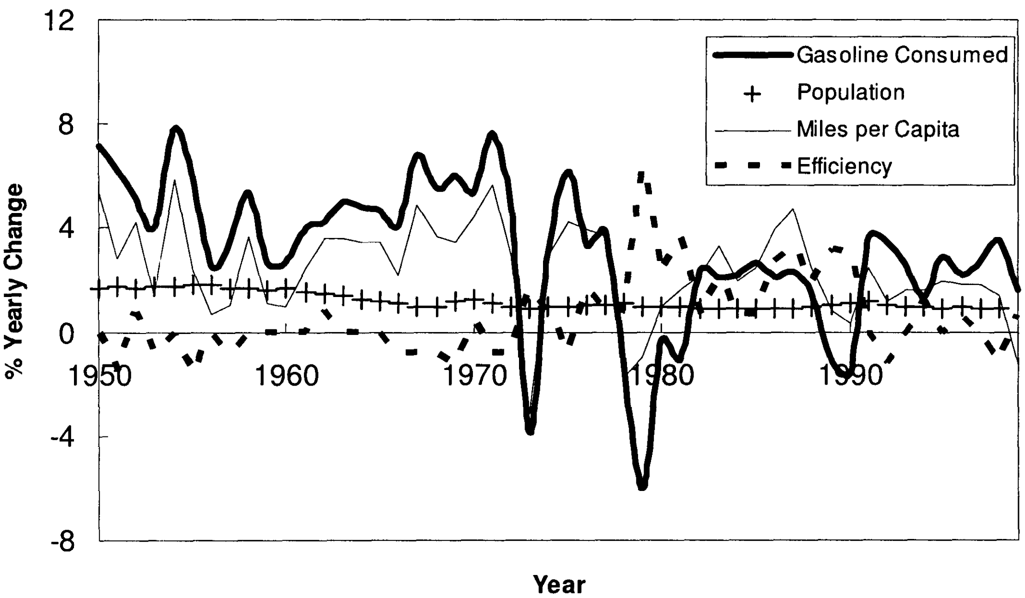

Figure 11: Gasoline Consumed, Population, Miles per Capita, and Vehicle Fuel Efficiency (1950-1999). Percent yearly change calculations for the IPM(1/E) equation shows that change in fuel consumed is most closely related to the amount of miles the average American is driving each year (BC 1997a, BC 1997b, DOT 2003a, DOT 2003b, CB 2000).

Figure 11 calculations were arrived at by taking the yearly change and dividing by the fist of the two years. In equation 3, "v" is the value of one of the variables during a given year "y". In effect, the percent yearly change shows how fast the variables change each year, similar to taking the first derivative. For example, the population data is an excellent representation of how the population of the US is constantly increasing.

$$\% \text{ Yearly Change} = [v(y+1)-v(y)]/v(y)*100 \qquad (3)$$

An IPM(1/E) analysis can be useful in determining relationships, or lack there of, between any of the variables. It is reasonable to assume, and it is evident by examining figure 11, that changes in population has a negligible effect on change in the driving behavior or change in the vehicle fuel efficiency. Also the wider range of vehicle fuel efficiencies in the latter half of the time period suggests that it is more loosely correlated to gasoline consumed and miles per capita. The relationship between miles per capita and efficiency, however, will be covered in more detail later in the explanation of the rebound effect. Gasoline consumed seems most closely correlated to the miles per capita. The gap between the impact line and the behavior line, most clearly seen in the first half of the period, is most likely due to the steady increase in population.

For refrigerators then, it is useful to do a similar analysis to the one done for automobiles. Figure 12 shows the calculations of percent yearly change of electricity use, number of refrigerators in use, and the inverse average efficiency of the refrigerators in operation. Yearly change in refrigerators per household is excluded because it is assumed a constant value throughout the time period in question. The inverse of the efficiency (kWh/year) is shown to be able to see the relationship between efficiency and total electricity use more clearly.

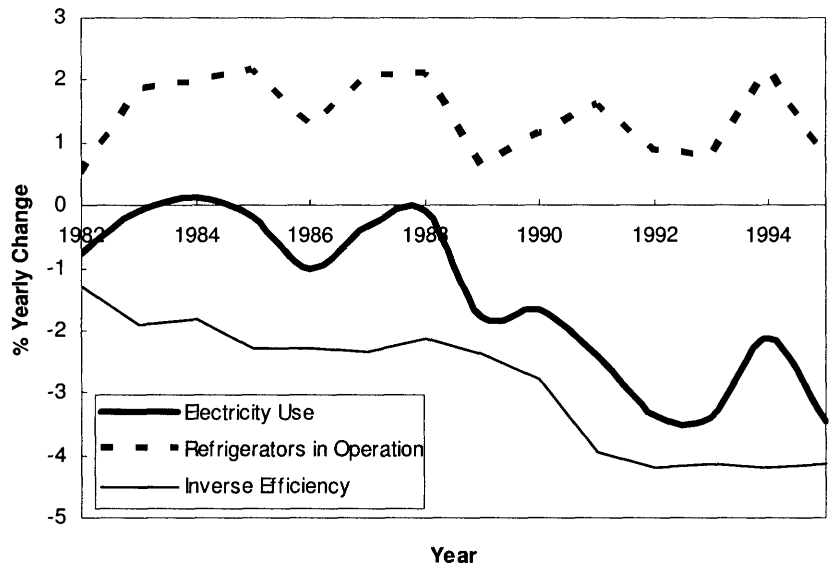

Figure 12: Electricity Use, Refrigerators in Operation, and Inverse Efficiency (1982-1995). Percent yearly change calculations for refrigerators from 1982 to 1995 shows what effect the change in the inverse of efficiency and change in number of refrigerators has on the change in total electricity use (Battles 2005, CB 2003, EIA 1993, EIA 1997, Rosenfeld 1999).

Figure 12 shows that, in the case of refrigerators, the change in electricity use is more closely related to a change in inverse efficiency. It is interesting to note however, that the electricity use line does not match the inverse efficiency line exactly. The peaks match those seen in the refrigerators in operation broken line. Also the gap between the electricity use line and inverse efficiency line is most likely due to the constant increase in refrigerators in operation.

Equation 4 is the condition for decreasing yearly change in gasoline consumption or electricity use. In the case of refrigerators the change in the number of refrigerators in operation is the only component on the right side of the equation.

$$\Delta E/E \geq [(\Delta P/P)+(\Delta M/M)] \quad (4)$$

Ten year averages for the parameters seen in equation 4 reveal that efficiency has never been able to reduce automobile fuel consumption on enough to satisfy equation 4. In the figure 13 calculations, everything to the upper left of the constant impact line is where population and miles per capita dominate. Everything to the lower right is where efficiency would dominate.

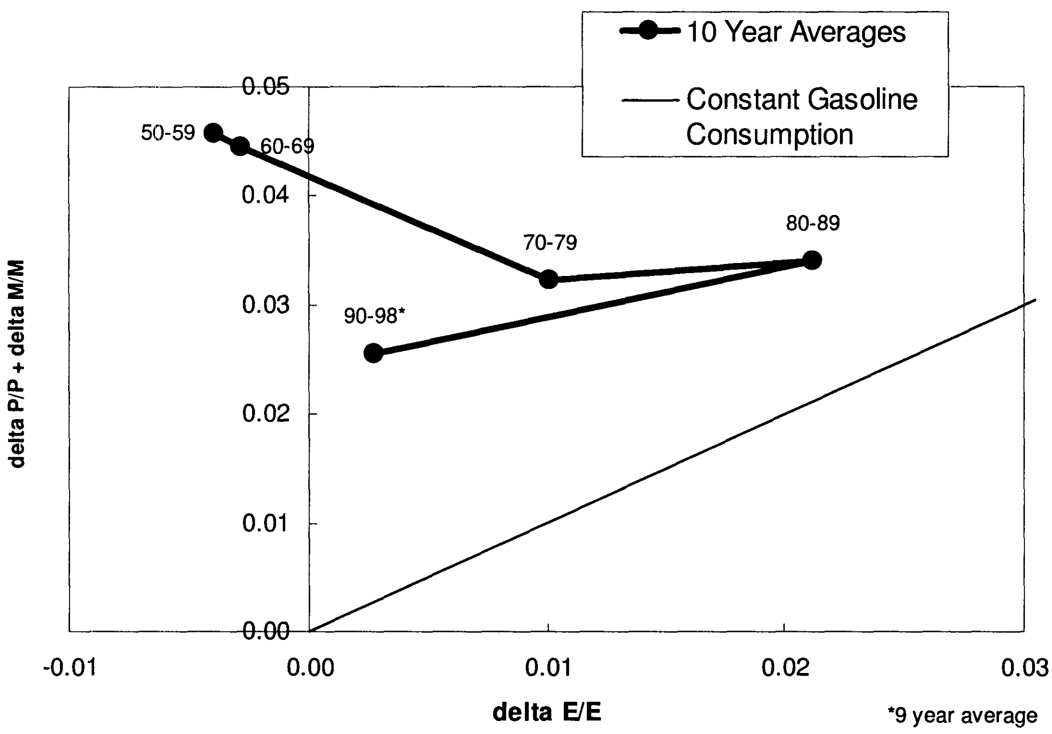

Figure 13: Change in Efficiency vs. Change is Population and Change in Miles per Capita for Automobiles (1950-1998). The calculations show that there are no ten year spans for which efficiency dominated population and miles per capita (BC 1997a, BC 1997b, DOT 2003a, DOT 2003b, CB 2000).

Figure 14 for refrigerators shows all of the two year averages after 1982 on or below the constant energy use line. Refrigerator manufacturers have been successful in collectively reducing the energy consumption of refrigerators, despite a growing number of units in operation.

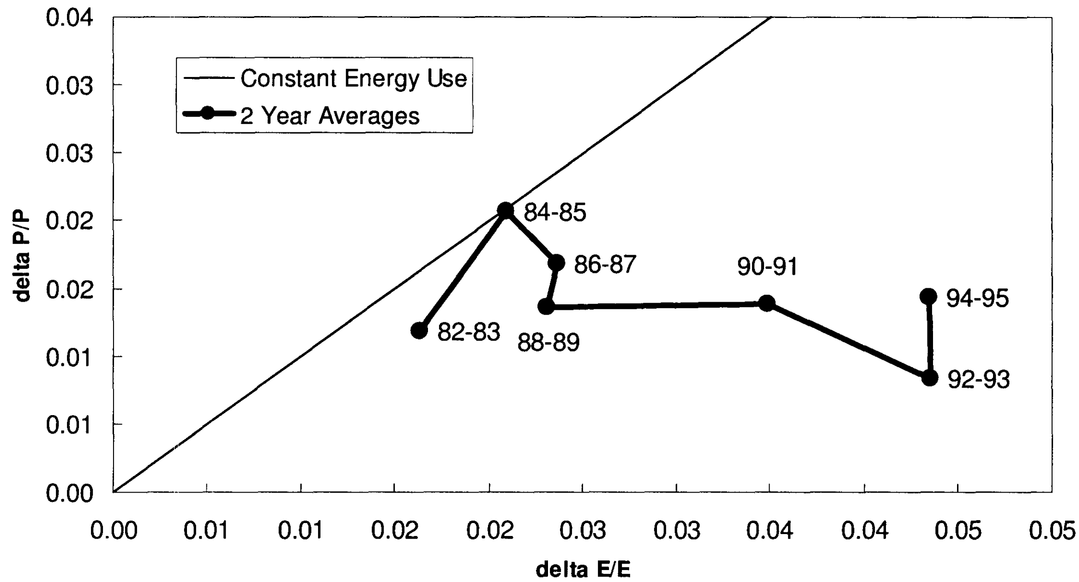

Figure 14: Change in Efficiency vs. Change in Refrigerators in Operation (1982-1995). After 1982, estimates for the energy consumption of refrigerators decrease on a yearly basis (Battles 2005, CB 2003, EIA 1993, EIA 1997, Rosenfeld 1999).

Phenomenon Seen During Price Shocks

Selected calculated values in figure 15 shows years when world events caused equation 4 to be satisfied for automobiles. In these cases the national supply droped to a level that effects price because of the price elasticity of gasoline. People either change their driving behavior because of availability of the supply or because of the price increase. The lower a point is in figure 15, the more people have altered their driving habits.

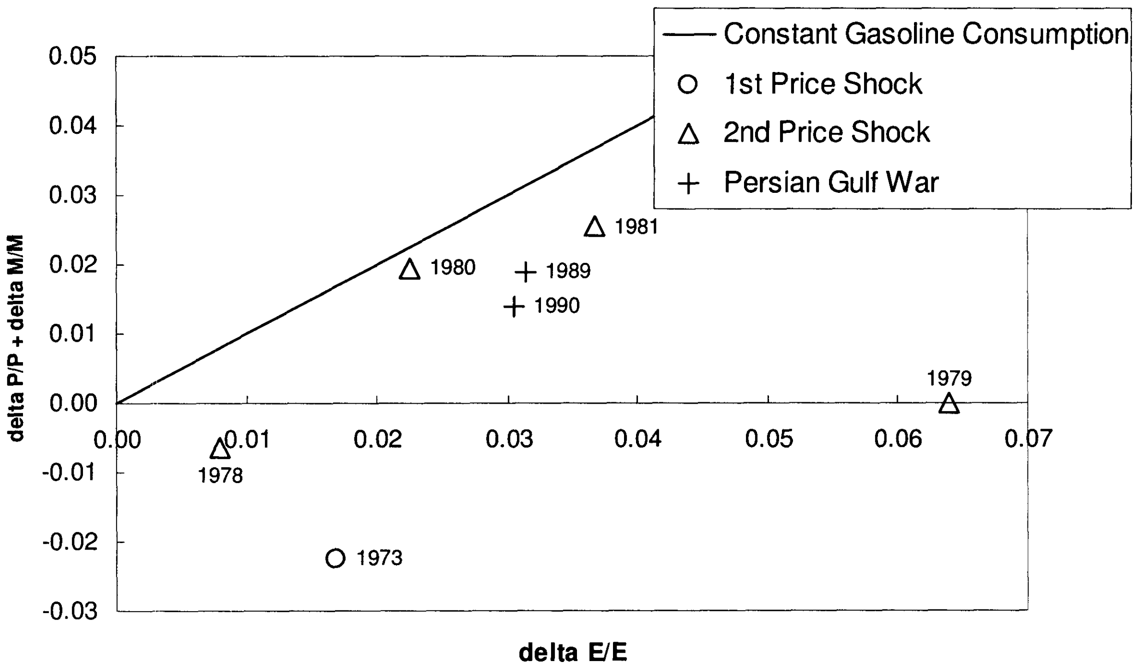

Figure 15: Price Shock Years. All of the calculations for price shock years lie to the lower right of the constant impact line (DOT 2003a, DOT 2003b, CB 2000).

Long Term Rebound Effect

When performing the adjusted IPAT equation analysis in the National Growth Analysis section, it was important to look for relationships between each of the variables on the right hand side of the equation. The relationship between efficiency and miles per capita is particularly important in the case of automobiles because improved technology gains are offset if efficiency causes people to drive more because the price per distance traveled is lower.

Figure 16 shows efficiency data vs. miles per capita calculations for the last half of the 20th century. The near vertical lines, from 1950 to about 1975 and from 1990 to 2000, indicate that people were driving more on average regardless of overall fleet efficiency improvements. The time period from about 1975 to 1990 shows efficiency and driving behavior changing with each other. This trend may or may not be an indication of the relationship between the two variables.

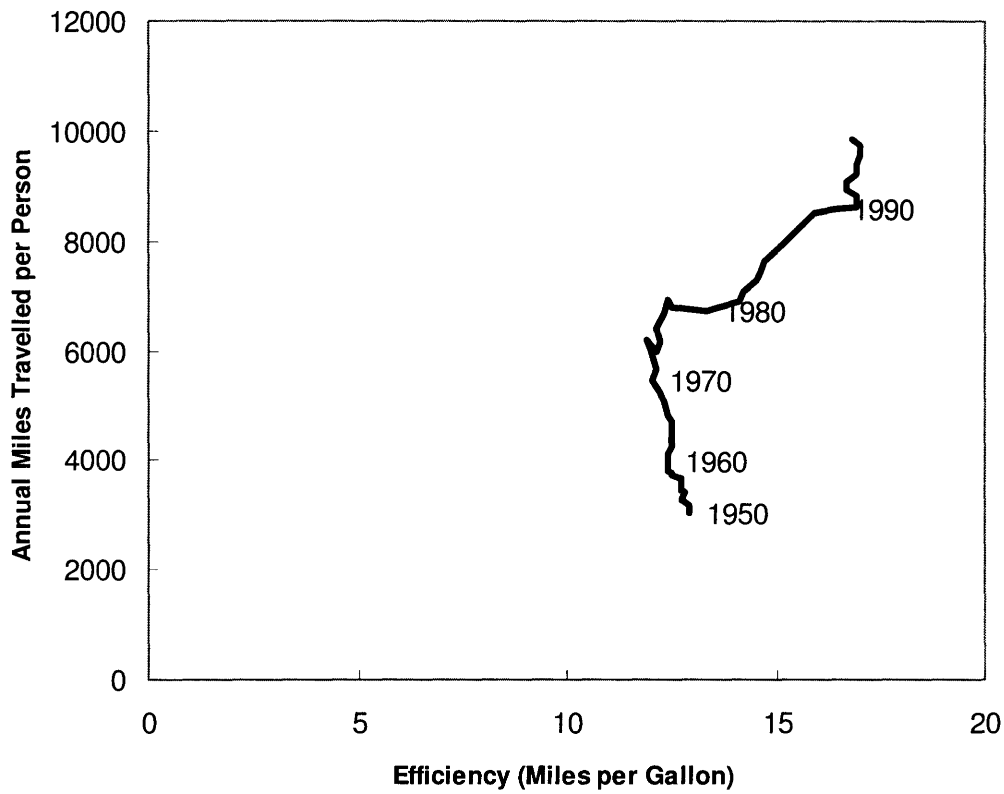

Figure 16: Efficiency vs. Miles per Capita (1950-1999). One region in particular, from about 1975 to 1990, shows a rebound effect for which there is nearly a direct relationship between efficiency and annual miles driven per person (BC 1997a, BC 1997b, CB 2000, DOT 2003a, DOT 2003b).

One reason to believe that the rebound effect is negligible is that the miles per capita graph, figure 2, shown in the data section has a relatively constant positive slope, despite significant changes in efficiency throughout the years. Refrigerators do not exhibit the rebound effect because again their user behavior is constant.

Effective Efficiency Regulation

The CAFE standards have been effective in increasing the corporate fleet average fuel efficiencies since the first year of their enforcement. Regardless, the total amount of fuel consumed in the US by automobiles continues to increase due to other factors, such as people's relentless desire to drive more. The fact that the standards have not been changed dramatically has led to a decrease in the average domestic and foreign truck fuel economies in recent years (figure 3). In general, from 1978 to 1984 manufacturers used improvements in engine technology to improve fuel economy and from 1984 to present, improvements in engine technology have gone towards performance. This issue is something the National Research Council addressed in their study *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards* (NRC 2002).

Unfortunately, Americans are used to their high powered cars and struggling US automobile manufacturers are aware of the costs associated with changing their production lines to incorporate existing fuel saving technologies that are not currently in vehicles (Heywood et al 2000). The government, aware of these problems, and the possible economic ramifications of imposing standards that are too difficult to meet, is reluctant to change the system. Only modest adjustments have been made to the standards in recent years. Representatives against changing the standards have used safety as an argument against radical changes to the current system (concepts aimed at weight reduction as a viable option to improve fuel economy), despite the fact that studies on safety have been inconclusive at best.

Amongst opposition, the committee argues that the standards are not accomplishing the goals set forth in response to the energy crisis in the 1970's. They suggest a new standard called E-CAFE, which addresses the weight reduction issue by seeking to force new cars into a more narrow weight range, eliminates the two class distinction that has resulted in crossover vehicles that take advantage of the lower standards for light trucks, and corrects for the current lack of standards for vehicles over a certain weight. While their idea is highly speculative its potential benefits, adjustability to encourage future progress and the elimination of ambiguities in the standards, sound promising. Even so, the standards only directly target efficiency, as suggested in the National Growth Analysis section, not user behavior (NRC 2002).

The idea of federal and state governments using gasoline taxes to discourage people from driving is another option. Advocates of a higher gasoline tax, similar to the Natural Capitalists, argue that taxes today do not take into account certain externalities: local air pollution, carbon dioxide emissions, traffic congestion, traffic accidents, and oil dependency (Parry 2002). One issue with the proposed higher tax, however, is its regressive nature, the fact that it would impact the poor more than the wealthy. Figure 17 shows calculations of tax as a percentage of retail price, and expenditures of gasoline at retail price as a percentage of the average Americans disposable income. Average annual expenditure on gasoline is the product of miles traveled per person, inverse fuel efficiency, and retail price.

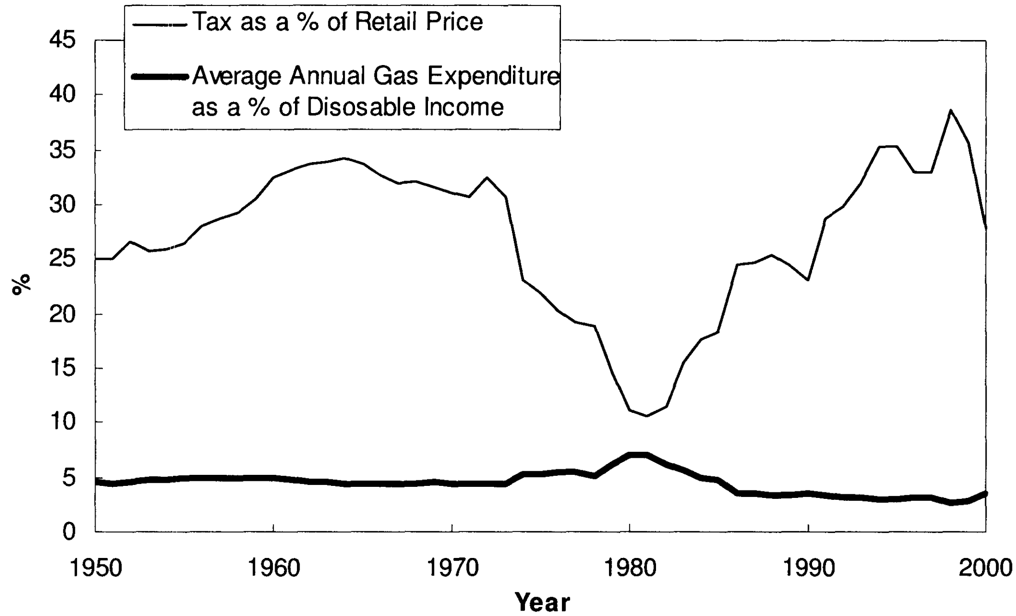

Figure 17: Gasoline Tax and Gasoline Expenditures (1950-2000). The pinch point right after 1980, the second price shock, represents a time when the cost of crude oil, refining, and distribution were unusually high (API 2003, BC 1997b, CB 2002, DOT 2003a, DOT 2003b, EIA 2003).

The US government has been hesitant to change the tax rates dramatically to rates similar to European rates because cheap energy has been an American staple. The fear of the economic consequences and the need to implement tax shifts prevents higher taxes from coming into effect. Likewise, there is no tax on electricity to encourage people to replace their older less energy efficient appliances.

In the case of refrigerators, however, regulations on efficiency have been effective. A minimum efficiency was set for each of the five years shown in figure 8, they were met by manufacturers at a marginal cost without the need for breakthrough technology, and consumption fell as a result. Here the situation back in 1976 is described, right before the first refrigerator standards came into effect:

> David Goldstein and I discovered that there was absolutely no correlation between refrigerators retail price and efficiency, although we controlled for every feature we could image…if the standards eliminated the least efficient half of the units, the consumer would notice no change in purchase prices, but would save some $350 over the 16-year appliance service life (Rosenfeld 1999).

The effectiveness of regulation is highly dependent on the realities of what gains are possible at what price. For example, it may be unreasonable to assume that the efficiency of the average automobile will reach 50 to 60 miles per gallon to allow for pre-1973-embargo national consumption levels, without considerable cost to everyone. Manufacturers would certainly have to adjust their production, and millions of Americans would have to retire their old vehicles and substitute with the most efficient cars available. One difference between automobiles and refrigerators is the price that can be associated with improved efficiency. The cost for the added efficiency of the 2005 Honda Civic Hybrid is an additional $4,300 over the comparable non hybrid sedan model (Honda 2005). In contrast, for refrigerators the cost difference is negligible, as mentioned by Rosenfeld above.

Conclusion

This thesis attempts to discover the effect of efficiency on the energy consumption of automobiles and refrigerators. Improving efficiency alone as a means to decreasing consumption has its limits. Economists, for example, would argue that increasing efficiency stimulates increased usage. On the other hand, imposing regulations that focus on efficiency is more realistic than expecting people to conserve without imposing restrictions that impinge upon personal freedoms.

The data shows that while efficiency improvements have not reduced total fuel consumption of US automobiles, they have led to the decreased electricity consumption of refrigerators. From 1982 to 1996, the amount of electricity consumed by refrigerators in the US each year fell significantly, from 137 billion kWh to 111 billion kWh. This improvement was in spite of a 19% increase in the number of refrigerators in operation. By comparison, in 1982 US automobiles consumed 114 billion gallons of fuel, and in 1996 this figure rose to 147 billion gallons.

Imposing sufficient refrigerator standards was possible because they did not require huge technological breakthroughs or changes in user behavior, making them financially feasible for both manufacturers and consumers (Rosenfeld 1999). Heywood's study proves that technological options exist for automobiles, but that they must be too expensive or else they would have been implemented already. Also compared to refrigerators, there is a much higher demand for transportation services. This point can be illustrated by the fact that the number of refrigerators per household has remained constant (figure 6), but the average number of miles driven per year has increased (figure 2). The refrigerator success story is a good indicator that thoughtful and constantly updating standards can make a difference. In contrast, any revisions to the CAFE standards face political obstacles because the government is going to be cautious about putting restrictions on automobile manufacturers' ability to satisfy the demand of their customers.

The effort to reduce the energy consumption of automobiles has to become a higher political priority in the US. The government is capable of and responsible for responding to energy consumption challenges by finding a solution that works, perhaps some kind of revenue neutral system that encourages drivers to trade in their current vehicles for more economical and efficient ones. The combination of regulated and market driven technological improvements with an energy conscious public can reverse the trends.

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