THE IMPLICIT COST OF CARBON UNDER CASH FOR CLUNKERS AND APPLIANCE REBATE PROGRAMS

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The Implicit Cost of Carbon under Cash for Clunkers and Appliance Rebate Programs

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Abstract

Cash-for-clunkers was a program designed to stimulate the economy and reduce greenhouse gas emissions. Now, the government is initiating a new plan that will provide rebates for household appliances. This research presents estimates of the cost of reducing Carbon Dioxide under Cash-for-clunkers and similar programs for both clothes washers and refrigerators. The estimates suggest that these rebate programs are an expensive way to reduce CO2 emissions. With an average rebate of $4215, baseline scenarios indicate that Cash-for-clunkers costs $370.26 for a one metric ton reduction in CO_2, and $414.62 per ton when the scenario includes the incentive to drive more that accompanies owning a more fuel efficient vehicle. The baseline scenarios for refrigerators resulted in a lower cost of $302.03 per metric ton of CO2, while clothes washers were more expensive with a price of $734.68 per metric ton of CO_2.

KEYWORDS: (Cash-for-clunkers, Rebate, Refrigerator)

ON MY HONOR, I HAVE NEITHER GIVEN NOR RECEIVED UNAUTHORIZED AID ON THIS THESIS

Signature

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

On July 27, 2009 the US government announced the start of the popular Cash-for clunkers rebate program. During the 29 days of the program, Cash-for-clunkers subsidized 690,114 new vehicles, and condemned an equivalent number of old inefficient vehicles to be scrapped and recycled.[1] Policymakers advertised the program as an effective stimulus and environmental program. For this spring, 2010 policymakers are planning to introduce a rebate program for Energy Star rated household appliances. The following chapters are devoted to comparing the effectiveness of Cash-for-clunkers to a similar program for refrigerators and clothes washers.

Policymakers claimed that renewing the vehicle fleet through Cash-for-clunkers would result in substantial reductions in Carbon Dioxide (CO2) emissions. The scenarios in the following chapters estimate that the program was actually relatively expensive, resulting in the government paying between $370.26 and $414.62 to avoid the release of one metric ton of CO2 into the atmosphere. This study also finds that for the baseline scenario a similar program for refrigerators yields a price of $302.03 per ton of CO2, and a program for clothes washers results in $734.68 per ton of CO2. These prices are all well above the cap and trade market price of CO2 in Europe, which was about $38.94. per

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[1] Car Allowance Rebate System. Official Information [Updated Feb. 22, 2010; Cited Feb. 24. 2010]. Available from http://www.cars.gov/official-information

metric ton last summer 2009, but has now dropped to below $15.58 due to the financial crisis.[2]

Since the late 1980s the world has become increasingly more aware of global climate change. The world's temperatures have been steadily on the rise throughout the 20th and 21st centuries due to the release of greenhouse gases into the atmosphere. Global climate change has widespread implications to the world's ecosystems. Not only is it expected that temperatures will change, but precipitation patterns can change as well. Africa has experienced extended droughts and the desertification of former croplands. Temperatures in the Arctic have seen the largest increase with vast decreases in sea ice cover during the spring. According to the Intergovernmental Panel on Climate Change (IPCC) eleven of the twelve years between 1995 and 2006 rank among the twelve warmest years since 1850.[3] The largest contributor to greenhouse gas is CO2, which is most commonly released from the burning of fossil fuels. Greenhouse gases trap heat in earth's atmosphere that would normally be reflected back into space. There are many types of greenhouse gases, but carbon dioxide poses the most pressing issue, since it can stay in the atmosphere for over 100 years. This fact makes global climate change especially dangerous, because it is very difficult to reverse and, can if not slowed, result in a positive feedback warming cycle. In the global north as snow cover decreases more heat is absorbed in the ground rather than reflected by the snow resulting in an

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[2] Financial Crisis Drives Down Price of Pollution. Jan. 26, 2009. Spiegel Online International. [Cited Feb. 25, 2010]. Available from http://www.spiegel.de/international/europe/0,1518,603521,00.html

[3] Observed Changes in Climate and Their Effects. IPCC Fourth Assessment Report: Climate Change 2007. Available from http://www.ipcc.ch/publications_and_data/ar4/syr/en/mains1.html

accelerated warming effect. The largest growth in greenhouse gas emissions including CO_2 has come from energy supply, transport, and industry.[4] The United States has historically been the largest emitter of CO_2 and has only recently been surpassed by China. One of the primary problems in the US is the huge vehicle fleet that has not experienced any substantial increase in efficiency in the last 30 years.

Figure 1.1

Adjusted Fuel Economy by Model Year (Annual Data)[5] [6]

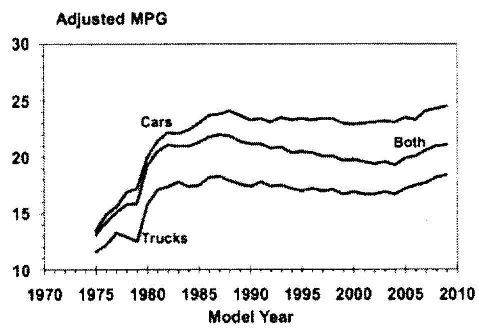

Figure 1.1 demonstrates that recent improvements in the average fuel efficiency of the US car fleet has only managed to raise efficiency to levels close to the average fuel efficiency in the mid 1980s. Although technology for the most fuel-efficient cars has improved tremendously with some hybrid vehicles getting more than 45 miles per gallon, these vehicles have not experienced sufficient market penetration to significantly lower

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[4] ibid

[5] Emission Facts: Greenhouse Gas Emissions from a Typical passenger Vehicle. US EPA. Overview: Pollutants and Programs. Febuary 2005. Available from http://www.epa.gov/otaq/climate/420f05004.htm#step2

[6] The EPA provides consumers with the adjusted fuel economy, which includes: combined highway and city driving, higher highway speeds, aggressive driving, and greater use of air conditioning.

CO_2 emissions. One way to achieve significant reductions in CO_2 emissions in the United States is to upgrade the vehicle fleet with much more fuel-efficient vehicles. This can be done through higher fuel prices or programs that subsidize more efficient vehicles.

Cash-for-clunkers allowed individuals with old inefficient vehicles to receive a $3500-4500 trade-in rebate on a new more fuel-efficient vehicle. The trade-in vehicle was required to be less than 25 years old, have a new, combined city and highway fuel economy of 18mpg or less, and be in drivable condition. Additionally Cash-for-clunkers required the vehicle to be continuously insured and registered to the same owner a full year preceding the trade-in. The rebate amount depended on the type of vehicle purchased and the difference in mpg between the trade-in and new vehicle. Trade-in of large work trucks were based on slightly different criteria.[7] The program was touted as a way to get the oldest higher polluting vehicles off the road while upgrading the new fleet as well. Cash-for-clunkers was immensely popular and the government extended its original 1 billion dollar budget to almost 3 billion.

Following the Cash-for-clunkers program, which ended August 2009, the government is now providing almost 300 million dollars for rebates on household appliances. These rebates are expected to range between $50-200, and will become available around March 2010.[8] Unlike cash for clunkers, the government will not be

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[7] Car Allowance Rebate System. Official Information [Updated Feb. 22, 2010; Cited Feb. 24. 2010]. Available from http://www.cars.gov/official-information

[8] Approved Energy Efficient Appliance Rebate Programs. US Department of Energy. Energy Efficiency and Renewable Energy. [Updated Feb 25, 2010; Cited Feb 25, 2010]. Available from http://www.energysavers.gov/financial/70022.html

managing all the rebates, but will be providing funding to individual state programs. The states will be determining their own specific program conditions and rebates. Additionally, it is not expected that the consumer will have to trade-in an old appliance; they will instead receive a direct rebate if they purchase an energy star rated appliance. However, the scenarios in the chapters below assume that the appliance program would be identical to Cash-for-clunkers in order to achieve a more accurate comparison of their environmental impacts.

Many older household appliances are incredibly energy inefficient. Federal appliance efficiency standards have resulted in an efficiency improvement of over 150% for residential refrigerators between 1980 and 2002.[9] Clothes Washers have also improved in efficiency, with some energy star rated models using less than a third of the energy of a model year 2000 top-loading machine. In addition to the energy savings, front-loading energy star washing machines sometimes use 50% less water than the conventional top-loader.[10]

The US is not the only nation to employ economic stimulus programs that improve the environment. After the global economic crisis, European countries are also creating stimulus packages that promote their environmental goals. They are focusing on areas where climate policies are already in effect, but the carbon price and other regulations are not sufficient to induce change. This is true for new carbon capture

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[9] Kim, Hyung C., Gregory A. Keoleian, and Yuhta A. Horie. 2006. "Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost." Energy Policy 34, no. 15 (10) : 2310-2323.

[10] Energy Star. "Clothes Washers Qualified Products." EPA and DOE, [Updated 2009; Cited November 2010]. Available from http://www.energystar.gov/index.cfm?c=clotheswash.pr_clothes_washers

technology and large infrastructure developments that need funding to be put into motion. Germany has invested in new infrastructure, mostly based on emission and energy savings through better insulation. They are also promoting emissions savings due to a minimum share of renewable energy in new private homes. Additionally the EU is concentrating on improving the energy sector, which is looking to receive a 3.9 billion euro infrastructure package. [11] A large portion of this stimulus package will go to building new electricity inter-connectors to Eastern Europe. The rest of the package includes over half a billion on wind projects, and 1 billion earmarked for the development of carbon capture storage (CCS) power plants. The EU is investing in new building infrastructure, renewable energy, and new environmental technologies such as CCS in order to stimulate the economy and reduce green house gas emissions. [12]

The following chapters are devoted to investigating the amount of money the US government is spending to reduce CO2 emissions through the Cash-for-clunkers program. It then proceeds to create scenarios similar to Cash-for-clunkers for household appliances in order to determine the relative environmental efficiency of these programs. The first chapter reviews the available literature on Cash-for-clunkers and household appliances, with an emphasis on literature discussing optimal life cycles of products. The next three chapters explain the effectiveness of rebate programs through potential scenarios for Cash-for-clunkers, and similar programs for clothes washers and

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[11] Nuthall, Keith. "EU to help power sector through recession." June, 2009. Wilmington Business Information. Modern Power Systems. www.modernposwersystems.com.

[12] Droege, Susanne. 2009. Climate Policy and Economic Bust: The European Challenges to Create Green Stimulus. *Carbon & Climate Law Review* 3, no. 2 (12) : 135-142.

refrigerators. This analysis has the potential to provide useful information for policymakers and future rebate programs.

CHAPTER II

LITERATURE REVIEW

This chapter reviews the literature about the effectiveness of the Cash-for-clunkers program. It also reviews literature on household appliances such as refrigerators and clothes washers and their effect on the environment. These studies include information about the federal appliance energy standards, inducted in 1990, and the Energy Star program created by the Environmental Protection Agency (EPA) and Department of Energy (DOE) to promote energy efficient home appliances. Table 2.1 gives a brief overview of all the scholarly journal articles consulted in this literature review.

Table 2.1

Previous Studies

Authors	Study	Findings
Patrick S. McCarthy (1996)	Market Price and Income Elasticities of New Vehicle Demands	Based on extensive new vehicle survey from 1989 price and income elasticity of demand are -.87 and 1.70 respectively.
Jonathan G. Koomey, Susan A. Mahler, Carrie A. Webber, James E. McMahon (1999)	Projected Regional Impacts of Appliance Efficiency Standards for the US Residential Sector	A minimum efficiency standard was put in place for many residential end uses. These include normal household appliances such as refrigerators, freezers, washing machines and dishwashers. From 1990 to 2010 these energy savings are projected to have saved $33 billion after subtracting the price of more efficient equipment.

		Projected carbon reductions are 9 million metric tons per year.
C.A. Webber, R.E. Brown, J.G. Koomey (2000)	Savings Estimates for the Energy Star Voluntary Labeling Program	The Energy Star program has saved 760 petajoules of energy since it began in 1993 (data from 2000). This results in 5.2 billion dollars in energy bill savings. If the year 2000 savings are taken into account this could potentially reach an additional 370 petajoules and 2.5 billion dollars. Savings estimates through 2010 range from 40-57 billion, or $150 billion with 100% market penetration of energy star products.
Caleb Stewart, Mir-Akbar Hessami (2002)	Greenhouse Gas Emissions Due to Power Consumption of Household Whitegoods Appliances.	Stewart and Hessami use energy data from the years 1993-1999 to estimate total carbon emissions for 1994-2009 in Australia. It shows a peak of 29.6 mega-tons CO around 1999 and a decreasing trend to an estimated 27.4 mega-tons in 2009. Analysis for selected appliances show that refrigerators account for over half the total emissions decreasing from 60.1% in 1994 to 51.6% in 2009. During this time period clothes washers and dryers did not experience the same improvement.
S. Meyers, J.E. Mcmahon, M. McNeil, X. Liu (2003)	Impacts of US Federal Energy Efficiency Standards for Residential Appliances	Energy efficiency standards on residential appliances are expected to cut greenhouse gas emissions 8-9% by 2020 compared to levels without standards. This would amount to consumer benefit of $80 billion in 2015 and $130 billion by 2030.
Hyung Chul Kim, Gregory A. Keoleian, Darby E. Grande, and James C. Bean (2003)	Life Cycle Optimization of Automobile Replacement: Model and Application	Continued use of older inefficient cars is undermining the recent progress in automotive technology. This study determines that optimal lifetimes based on environmental concerns for cars built in the 80s or early 90s is 3-6 years. While life spans of cars build in the early 2000s is 7-14 years.
Hyung Chul Kim, Gregory A. Keoleian , Yuhta A. Horie (2005)	Optimal Household Refrigerator	In the time period 1985-2020 the optimal refrigerator life in terms of energy consumption and green house

	Replacement Policy for Life Cycle Energy, Greenhouse Gas Emissions, and Cost	gas emissions varied from 2-12 years. The cost simulation shows that the optimal lifespan when only looking at consumer cost is 17-19 years. This shows that there is a discrepancy between the two simulations. A government subsidy could be a solution to solve the problem.
Richard Bole (2006)	Life Cycle Optimization of Residential Clothes Washer Replacement	The life cycle optimization model indicates the critical importance of the use phase of clothes washers in the time period 2006 to 2020. It indicates that clothes washers should be replaced frequently both in terms of energy and carbon dioxide emissions. The baseline scenario indicates replacements every 5 years.
Denise Young (2007)	When do Energy-Efficient Appliances Generate Energy Savings? Some Evidence from Canada	Young analyzes life spans of Canadian appliances. Dishwashers tend to be replaced the most frequently, while over 40% of freezers are in use for more than 20 years before being retired. Socioeconomic factors related to appliance replacement such as income provide some evidence that a program to promote the earlier replacement of these appliances might be a useful policy tool.
Denise Young (2007)	Who Pays for the 'beer fridge'? Evidence from Canada	Many Canadian households use a secondary fridge often known as a 'beer fridge.' Older vintage beer fridges are costly for households and are bad for the environment. Removing beer fridges or changing to more efficient fridges could substantially reduce energy use and green house gas emissions. The problem is that because of household income levels and low energy prices running an additional beer fridge is very inexpensive.
Kenichi Mizobuchi (2008)	An Empirical Study on the Rebound Effect Considering Capital Costs	Technological progress can reduce energy usage and CO2 emissions, but this in turn leads to a reduction in the real cost of energy, which causes an increase in demand for energy. A

		reduction in the projected CO2 emissions due to improved technology can sometimes be offset, because of the real cost reduction.
Marla C. Sanchez, Richard E. Brown, Carrie Webber, Gregory K. Homan (2008)	Savings Estimates for the United States Environmental Protection Agency's ENERGY STAR Voluntary Product Labeling Program	The energy star program through 2006 has been responsible for saving 4.8 EJ of primary energy. The program saved approximately 47 billion dollars in energy bills. Unlike the other analysis this article focuses on new energy, star products not including refrigerators washing machines, etc. The primary energy savers in this report were computers, monitors, printers, and residential light fixtures. The study projects that through 2015 the program will save 12.8 EJ. The energy bill savings from this projected increase in energy star products would amount to approximately $90 billion.
Larry Dale (2008)	An Analysis of the Price Elasticity of Demand for Household Appliances	The report analyzes price elasticity of demand for refrigerators, clothes washers, and dishwashers. It performs a regression analysis on the shipments of home appliance and relevant economic variables. The study estimates the price elasticity of demand for refrigerators and clothes washers at -.4 and -.31.
Allan, Alexander, Rachael Carpenter and Geoff Morrison	Abating Greenhouse Gas Emissions through Cash for Clunker Programs	This study discusses design considerations for a vehicle scrappage program based on reducing greenhouse gas emissions. It then gives the basic design for a program that at least offsets GHG emissions attributable to the end life and construction of a new vehicle.
Cristopher R. Knittel (August 2009)	The Implied Cost of Carbon Dioxide Under the Cash-for-clunkers Program	This study indicates that Cash-for-clunkers was an expensive way to reduce greenhouse gases. It assumes that the average annual vehicle miles for the clunker were 12000 and the difference in fuel efficiency between the clunker and the new vehicle was 9 mpg. Using these assumptions the article estimates the cost of removing

		one ton of CO_2 from the atmosphere. Conservative estimates exceed $365 per ton, while a best-case scenario puts the price at $237 dollars per ton.

Cash-for-clunkers

Recent progress in automotive technology has greatly increased fuel efficiency and exhaust emissions for new cars. However, these benefits have not been realized to their potential due to the continued use of old, inefficient, and higher-polluting cars. The problem is the discrepancy between the optimal life span of a vehicle based on private cost and the optimal life span based on environmental concerns. According to Chul K et al the estimated optimal environmental life for vehicles built in the 80s and late 90s is 3-6 years. The optimal environmental life represents the number of years that a car should be kept before new emission technology makes it better for the environment to purchase a new one. The same study found that vehicles from the 2000s have an optimal environmental life of 7-14 years.[1] However, during the same time period actual vehicle life spans have been increasing more dramatically. For example the same study puts median life in 1980 at 12.5 years, and the median life in 1990 at 16.9 years.[2] The difference between the optimal environmental life span of a vehicle and the median number of years it is kept in use allowed policy makers to introduce Cash-for-clunkers as an environmental program.

[1] Hyung, Chul K., Gregory A. Keoleian, Darby E. Grande, and James C. Bean. 2003. Life Cycle Optimization of Automobile Replacement: Model and Application. *Environmental science & technology* 37, no. 23 (12) : 5407-5413.

[2] ibid

The Cash-for-clunkers program was designed to stimulate the economy, provide relief for struggling automakers in Detroit, and also reduce greenhouse gas emissions. The program allowed car owners to trade in their old gas-guzzling vehicle in exchange for a 3500-4500 dollar rebate on a new more fuel-efficient vehicle. In the article "The Implied Cost of Carbon Dioxide Under the Cash-for-clunkers Program" Knittel analyzes the program's efficiency at reducing CO2 emissions. The study determines, using basic calculations, that in the best-case scenario the government was paying $237 for a one-ton reduction in CO2 emissions. When using more "reasonable" parameter values the model produced an approximate cost in excess of $500 per ton.[3]

In order to achieve these numbers Knittel keeps certain parameters about the old and new vehicle constant. He assumes that the driving habits of the old car and the new car are the same and the annual vehicle miles traveled would be 12000. The estimated difference in fuel mileage between the two cars is 9 miles per gallon. Using these assumptions the study calculates that the program saved 270 gallons for every year that the clunker vehicle would have been on the road. One burned gallon of gasoline emits approximately 20 pounds of carbon dioxide.[4] Using this data one can determine that the program saves about 2.7 tons of carbon for every year the clunker would have been on the road. If the clunker had survived another four years then the average cost per ton of

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[3] Knittel, Christopher R. 2009. "The Implied Cost of Carbon Dioxide Under the Cash-for-clunkers Program." *Center for the Study of Energy Markets* University of California Energy Institute, Available from http://www.ucei.berkeley.edu/PDF/csemwp189.pdf

[4] Allan, Alexander, Rachel Carpenter, and Geoff Morrison., 2009. "Abating Greenhouse Gas Emissions through Cash-for-Clunker Programs." Transportation Technology and Policy Group, Department of Civil and Environmental Engineering. University of California Davis.

CO_2 would be \$400. The study conducts various simulations that use different survival times and annual vehicle miles.

Knittel's results suggest that the program was not very effective in removing carbon dioxide from the atmosphere. Even the best-case scenario that resulted in a carbon cost of \$237 per ton of CO_2 is very expensive. This study, though in some ways primitive and not fully developed, suggests that Cash-for-clunkers was an expensive environmental program.

US Appliance Efficiency Standards

The federal residential efficiency standards were introduced in 1988 and took effect in 1990.[5] These standards were put into effect for a large number of residential end-use products such as refrigerators, clothes washers, clothes dryers, dishwashers, etc. The study from 1999 "Projected regional impacts of appliance efficiency standards for the US residential sector" explains that because the standards save energy at a cost lower than the price of the energy, the resulting reduction in carbon emissions are achieved at a negative net cost to society. The standards are not only better for the environment, but also result in the construction of more cost efficient appliances. This finding contradicts the view that the economy is efficient and therefore all emission reductions must come at a cost.

Koomey et al analyzes the projected savings from the new standards adjusting for estimated progress in appliance efficiency in the absence of those standards. This factor

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[5] Jonathan G. Koomey, Susan A. Mahler, Carrie A. Webber, James E. McMahon. 1999. Projected regional impacts of appliance efficiency standards for the US residential sector. *Energy* : 69-84.

equals 1 in the first year of the standard and declines as time passes. The rate of decline in the model is determined by historic increases in energy efficiency. This rate is calculated by dividing the historical annual trends in energy efficiency (%/year) by the percentage efficiency improvement due to each standard in the first year. This calculates the number of years it would take the baseline to overtake the improvement that would occur because of the induced standard. With this data the authors makes conservative calculations on projected savings. They find that the appliance standards saved 10.6 exajoules of primary energy between 1990 and 2010. The largest savings in this period come from showerheads, followed by gas water heaters and refrigerators. [6] This analysis suggests that the residential appliance efficiency standards have been a cost efficient policy for reducing energy use and carbon dioxide emissions.

The analysis published in 2003 performed a similar calculation including more recent updates on efficiency standards savings and projected savings through 2030. Meyers et al use actual data on products sold between 1987 and 1999 to examine energy savings due to standards. In almost all cases the actual energy efficiency exceeded the energy efficiency standard. [7] This could imply that when companies were forced to make their appliances more efficient it was often easy and made sense to improve them beyond the existing standard. In order to estimate energy savings the model uses a product retirement function to calculate the number of units in a given vintage year that are still in use and works under the assumption that appliance lifespan is normally distributed over a mean lifetime.

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[6] ibid

[7] Meyers, S., J. E. McMahon, M. McNeil, and X. Liu. 2003. "Impacts of US federal energy efficiency standards for residential appliances." Energy 28, no. 8 (06/15) : 755.

Using these parameters the study estimates that the standards will reduce CO2 emissions by 8-9% compared to projected levels without the standards, this will save 26-32 EJ by the year 2015 and 63 EJ by the year 2030. Meyers et al estimates that the benefits will reach nearly $80 billion by 2015 and $130 billion by 2030. Conversion factors for energy are found in table 2.2.

Table 2.2

Energy Conversion

1 Exajoule	10^18 Joules
1 Petajoule	10^15 Joules
1 kWh	3.6*10^6 Joules

The study shows the net benefit of the standards will be highest for refrigerators with clothes washers and water heaters falling into second and third place subsequently. [8] These standards have resulted in vast technological improvements of energy efficiency in household products. Additionally many appliances today go above and beyond these standards in energy savings, due to a program called "Energy Star," which labels products that are a certain percentage more efficient than the federal standards.

[8] ibid

Energy Star Program

Energy Star is a voluntary labeling program intended to promote energy efficient products. The program is a joint operation between the EPA and the DOE that began in 1992. [9] Today, Energy Star has become a leading international brand for energy efficient products. The program began with only a few products such as refrigerators, washing machines, and light fixtures, but has now been greatly extended to include items from computers to traffic signals.

In the two articles: "Saving estimates for the ENERGY STAR voluntary labeling program" (2000), and "Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program" (2008) the authors explain current energy savings from the program and make estimates for future savings.

The first article (2000) takes into account savings from office equipment, consumer electronics, residential heating and cooling, light fixtures, and new home appliances. Since its introduction in 1992 to the year 2000 the study shows that the program has saved 760 petajoules of primary energy for cumulative energy bill savings of $5.2 billion. When Webber et al include their projections for savings in the year 2000 total energy savings increase by 370 petajoules and an additional $2.5 billion.[10] During this time period energy star dishwashers, refrigerators, and clothes washers were 13%, 16%, and 47% more efficient respectively. Webber et al also provide a study that project savings based on a target market penetration case and a 100% market penetration case for the years 2001 to 2010. The target penetration analyzes each energy star product and

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[9] Webber, C. A., R. E. Brown. 2000. "Savings estimates for the ENERGY STAR* voluntary labeling program." Energy Policy 28, no. 15 (12) : 1137.

[10] ibid

predicts its market share based on price, energy prices etc. In this case 10,000 petajoules would be saved representing $63 billion. In the 100% penetration case 23,000 petajoules would be saved which represents $150 billion.[11]

The second article (2008) studies a large array of different consumer electronics, and certain commercial refrigerators, fryers, steamers and cookers, but does not address consumer white goods such as residential refrigerators, clothes washers, and dishwashers. Through 2006 the Energy Star program saved 4.8 EJ of primary energy and $47 billion. This study included over 40 product types, but six accounted for more than 70% of all energy star carbon reductions: monitors, printers, residential light fixtures, TV's, furnaces and computers. This study forecasts that over the period 2007-2015 the program will save 12.8 EJ of energy. [12]

These two articles illustrate how the Energy Star program has succeeded in achieving reductions in energy use, resulting in money savings and also substantial reductions in greenhouse gases. Both articles predict an increasingly important role for energy efficient products to meet future energy constraints and needs.

Refrigerators

In most homes today the refrigerator accounts for the largest amount of electricity use after heating and cooling systems. In 2001 Refrigerators accounted for 14% of

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[11] ibid

[12] Sanchez, Marla C., Richard E. Brown, Carrie Webber, and Gregory K. Homan. 2008. "Savings estimates for the United States Environmental Protection Agency's ENERGY STAR voluntary product labeling program." Energy Policy 36, no. 6 (06) : 2098-2108.

electricity consumption in US households.[13] Tightening standards have resulted in energy efficiency improving more than 150% between 1980 and 2002. Despite this fact people are continuing to use old, less efficient refrigerators. Kim Keolian and Horie estimate that the average lifetime of a fridge is over 14 years, with an optimal life when analyzing cost of 18 years. Initial product costs give consumers the incentive to maximize the working lifespan of the appliance. [14] This finding results in refrigerators that are exceedingly inefficient to be used for long periods of time. Additionally, deterioration of refrigerator components can sometimes result in 40-60% higher energy consumption. [15] In the Australian study "Greenhouse gas emissions due to power consumption of Household Whitegoods Appliances" Stewart and Mir-Akbar introduce a model to simulate the effect of aging on the household appliance. The model indicates that for refrigerators 5 to less than 10 years old the refrigerator will be 14% less efficient and at over 10 years old some refrigerators are 70% less efficient. [16] This huge difference is due to the wide range of refrigerators in the "*over 10 years old*" category. Some refrigerators get over 25 years of use and throw off the average.

The article "Optimal Household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost" studies the discrepancy between the

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[13] EIA, 2004a. Home energy use and costs: Residential Energy Consumption Survey. Energy Information Administration, Available from http://www.eia.doe.gov/emeu/recs/contents.html

[14] Kim, Hyung C., Gregory A. Keoleian, and Yuhta A. Horie. 2006. "Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost." Energy Policy 34, no. 15 (10) : 2310-2323.

[15] ibid

[16] Stewart, Caleb; Mir-Akbar Hessami. 2002. "Greenhouse Gas Emissions Due to Power Consumption of Household Whitegoods Appliances." Energy & Environment 13, no. 6 833-850.

optimum cost and optimum environmental lifespan of fridges. Kim, Keolian and Horie demonstrate that the use phase of the refrigerator accounts for 90% of its cycle energy use. This finding means that materials, manufacturing and disposal together account for less than 10% of total energy use. In order to determine loss of efficiency due to deterioration of insulation foam the authors used an equation derived from an empirical study and analysis by Johnson. The analysis estimates that refrigerators manufactured between 1985 and 2002 use 21% more energy per year after 10 years and those manufactured after 2003 will use 15 % more energy per year after 10 years. [17] The authors do not include the deterioration of other parts of the refrigerator because it has not been thoroughly studied. Since refrigerators consume the most energy in their use phase, it introduces the idea that there is cause to replace a refrigerator frequently when examining energy use and CO2 emissions. The problem is that the purchasing cost of a new refrigerator $430-670 (1985 dollars depending on model year) is by far the most significant cost for the consumer. The electricity cost $20-110 per year (1985 dollars) is much lower and will not have as great of a contribution to consumer choice.[18] The study results in optimum lifetime of a refrigerator in terms of CO2 emitted at 2,7,3,5,8,11 years for the time horizon 1985-2020. This means that the first refrigerator purchased in 1985 should be replaced in 2 years, that refrigerator should be replaced in 7 years and so on. Meanwhile, optimal lifespan in terms of private cost still gives the consumer the incentive to keep the refrigerator for 18 years, which is usually the entire functioning life

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[17] Johnson, R.W., 2003. The Effect of Blowing Agent Choice on Energy and Environmental Impact of a Refrigerator in Europe.

[18] Kim, Hyung C., Gregory A. Keoleian, and Yuhta A. Horie. "Optimal Refrigerator" 2006. 2310-2323

of the appliance.[19] The difference between the two optimum life spans suggests that in absence of an increase in the cost of energy some sort of rebate or subsidy is needed in order to bring the refrigerator life span closer to the optimal environmental lifespan.

Often when people decide to buy a new refrigerator they do not dispose of the old one. There is no incentive to get rid of a working appliance that could either be re-sold or continue to be used. In American households the old refrigerator will often be placed in the basement or garage and used as a beer, or soda fridge. In the Canadian study, "Who pays for the 'beer fridge'? Evidence from Canada," 30% of households surveyed operated a secondary fridge or 'beer fridge.' This study also showed that the median age of the secondary refrigerator was between 21-25 years. [20] This means that the secondary refrigerators would be using between 1000 and 1600 kWh of energy a year. [21] This information leads to the conclusion that if a subsidy or rebate is put in place there needs to be a method to ensure that the old refrigerator stops being used and is recycled.

Clothes Washers

The household clothes washer is another appliance that accounts for a large portion of electricity use in the home. Among household white-good appliances the clothes washer is the second largest electricity user after the refrigerator. In the Australian study projected 2009 values show the refrigerator accounting for 51.6% of total white-

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[19] ibid

[20] Young, Denise. 2008. "Who pays for the 'beer fridge'? Evidence from Canada." Energy Policy 36, no. 2 (02) : 553-560.

[21] Kim, Hyung C., Gregory A. Keoleian, and Yuhta A. Horie. "Optimal Refrigerator" 2006. 2310-2323.

good energy use, with clothes washers coming in second with 19.7%. [22] In this study Stewart and Mir-Akbar analyze refrigerators, freezers, dishwashers, clothes dryers, and clothes washers. Their data shows refrigerators as becoming increasingly more efficient, with clothes washers doing the same, but at a much slower rate. This finding explains why clothes washer percentage of total white-good energy use rose from 16.3% in 1994 to 19.7% in 2009. [23] The data presented by this study suggests that in Australia, although refrigerators have become much more efficient in the past 20 years, washing machines have not realized the same improvement. The US has also has not experienced a huge reduction in clothes washer energy use. This is because most families use less efficient top loading washing machines. The lack of improvement in efficiency seems strange when a typical clothes washer made in 1994 uses 767 kWh of energy a year, not accounting for degradation of components, while a new energy star washing machine sometimes uses as little as 150-200 kWh per year. [24] What explains this paradox is that the most efficient washing machine models are front loaders, which are considerably more expensive than the more conventional top loading washing machines. This is another situation where there is a discrepancy between the optimal cost and optimal environmental solution.

The study addressing the optimal life of clothes washers, similar to the previous study on refrigerators, gives information on how frequently clothes washers should be

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[22] Stewart, Caleb; Mir-Akbar Hessami. "Whitegoods" 2002. 833-850.

[23] ibid

[24] Energy Star. "Clothes Washers Qualified Products." EPA and DOE, http://www.energystar.gov/index.cfm?c=clotheswash.pr_clothes_washers

replaced. Energy efficiency of clothes washers in the US has increased by 88.4% between 1981 and 2003. [25] The use phase of the machine accounts for 96-99% of the energy, water, and carbon dioxide emissions, but results in about 61%-86% of the cost over an anticipated life of twenty years. The baseline model in the optimization study indicates that from an energy and carbon emission perspective any average washer should be replaced with a new front-loading machine in 2006 and the 2006 appliance should also be replaced in 2011 and 2016 subsequently. The cost perspective indicates a one-time replacement to the 2006 machine, which should be kept throughout the study period.[26]

The model considered different consumer scenarios. The baseline case assumes that natural gas fired water heater heats the water with 59% efficiency, and that a clothes dryer is used. The model analyzes the full laundry cycle including clothes drying, but uses a constant for the amount of energy use by the clothes dryer. The first of the three alternative scenarios assumes an electric water heater is used with 90.5% efficiency. The second alternative scenario assumes that no water heat is used. The third also uses this parameter, but assumes a dryer is not used as well. The first case recommends that the clothes washer should be replaced three times between 2006 and 2020 taking into account greenhouse gas emissions and energy use. The second scenario demands the same replacement scheme three times every 5 years. The third scenario that results in much lower energy use due to no warm water and air drying results in a one time replacement of all washers in 2006 and no additional replacement through the end of the

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[25] AHAM. Clothes Washers Energy Efficiency and Consumption Trends. Association of Home Appliance Manufacturers. June 1, 2005.

[26] Bole, Richard. "Life Cycle Optimization of Residential Clothes Washer Replacement." (Ph.D. diss., Center for Sustainable Systems University of Michigan 2006) Available from http://css.snre.umich.edu/css_doc/CSS06-03.pdf.

study period. [27] This study also recommends that a government incentive would be a useful tool in order to encourage people to replace clothes washers more frequently in accordance with the optimal environmental life span.

Price elasticity of demand of Household Appliances

The study "An Analysis of the Price Elasticity of Demand for Household Appliances" analyzes previous literature and available industry data to estimate the price elasticity of refrigerators, clothes washers and dishwashers. Dale chose these household products because they have the most available data. The study first performs a tabular analysis. This analysis uses data on demand due to housing starts and replacements and then proceeds to account the remaining change in demand to decreasing prices and increasing income. These two variables are assumed to have the same effect on demand. Dale used data from the year 1980 through 2002. The resulting price elasticity of demand for refrigerators, clothes washers and dishwashers are demonstrated in table 2.1. Residual shipments are defined as the difference between shipments and physical household demand, while relative total price is defined as appliance price plus the present value of lifetime appliance operating cost divided by household income.

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[27] ibid

Figure 2.1 [28]

Table 3.2 Tabular Estimation of Relative Price Elasticity of Demand

Appliance	Residual Shipments 1980	Residual Shipments 2002	Change (%)	Relative Total Price 1980	Relative Total Price 2002	Change (%)	Elasticity
Refrigerators	-0.532	1.597	30%	0.041	0.019	-74%	-0.40
Clothes Washers	-0.953	0.174	19%	0.028	0.013	-72%	-0.26
Dishwashers	-0.974	-0.005	23%	0.024	0.011	-76%	-0.30

In addition to the tabular estimation the study uses a simple regression model to estimate the impact of a few economic variables on shipments. Dale analyzes two different regression models. The first analyzes the appliances individually and the second finds one average value for all three appliances. The average price elasticity of demand for the first regression was -.4 for refrigerators, -.31 for clothes washers, and -.32 for dishwashers. The average was -.35, which is very close to the second combined regression value of -.34. [29]

Reviewing the literature available on Cash-for-clunkers and optimal environmental life spans of vehicles leads to doubts concerning the programs effectiveness as a means of reducing CO2 emissions. These doubts lead to further analysis of other products that are known to have large carbon footprints. The reviewed literature demonstrates that typical household items such as refrigerators and clothes washers use a substantial amount of energy and have large carbon footprints. Also due to recent efficiency standards inducted in 1992 and the new EPA and DOE Energy Star

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[28] Dale, Larry. 2008. "An Analysis of the Price Elasticity of Demand for Household Appliances."_2008. eScholarship. Lawrence Berkeley National Laboratory. Available from http://escholarship.org/usc/item/5qr2f2nz.

[29] ibid

appliance program there have been vast improvements in efficiency of these household products. After heating and cooling systems the refrigerator, and clothes washer account for the largest portion of the energy bill in a typical American household.

Research on these products suggests a discrepancy between their optimal environmental and optimal cost life span. Correcting the difference in optimal life spans, in absence of an increase in energy prices, would require some sort of rebate or subsidy. The information gathered on the three discussed household appliances leads to a gap in the few studies analyzing Cash-for-clunkers. Current information on the carbon footprint of household appliances leads one to the question whether a government rebate program for home appliances would be more effective in reducing CO2 emissions than Cash-for-clunkers.

CHAPTER III

CASH-FOR-CLUNKERS

Cash-for-clunkers was designed to both help the auto industry and to reduce CO2 emissions. The calculations in this chapter use parameters similar to Christopher R. Knittel's study: "The Implied Cost of Carbon Dioxide Under the Cash-for-clunkers Program." In Knittel's baseline scenario the government provides an average rebate of $4200 for the clunker vehicle, the average mpg difference between the old and new car is 9 mpg, and the driving habits are the same with both the new and old car being driven an average of 12,000 miles a year. Knittel uses data from a CNN report that estimates the average mpg for the clunker as 16.3 and the average mpg for the new vehicle as 24.8. Given that a gallon of gas produces approximately 20 pounds of CO2 when burned, Knittel determines that if the clunker would have been kept on the road for an additional 4 years without the program then the implied cost of cash for clunkers would be $416 per ton of CO2. If this is reduced to three years or increased to five years the implied cost would be $556 and $333 respectively.[1]

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[1] Knittel, Christopher R. 2009. "The Implied Cost of Carbon Dioxide Under the Cash-for-clunkers Program." *Center for the Study of Energy Markets* University of California Energy Institute, Available from http://www.ucei.berkeley.edu/PDF/csemwp189.pdf

Scenario 1

This first scenario is based on Knittel's calculations, but includes more recent values and puts answers into metric tons. The average Cash-for-clunkers discount was $4215.[2] Based on empirical studies, the EPA uses 12000 miles as the average annual miles for vehicles in the US.[3] The first step is to divide 12000 miles by 15.8 mpg and 12000 by 24.9 mpg and then find the difference between the two values.[4] The difference results in 277.57 gallons of fuel saved per year that the clunker would have been on the road. Using the EPA's estimate that burning one gallon of fuel equals approximately 22.29 pounds of CO2 one can convert 277.57 gallons per year into 2.81 metric tons of CO2 per year. [5] If the clunker would have survived another 4 years then the program would be paying $375.50, or $4215/11.23 tons, to avoid releasing 1 ton of CO2 into the atmosphere. If the potential lifespan of the clunker vehicle changes to 3 or 5 years the cost per ton of CO2 would be $500.65 and $300.40 respectively. The scenario does not take into account the energy used to recycle the old vehicle, because it represents such a

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[2] Consumer report estimates the average rebate to be $4215. "Government stalls the CARS program." [Updated July 30, 2009; Cited November 24 2009]. Available from http://blogs.consumerreports.org/cars/2009/07/cash-for-clunkers-government-stalls-the-cars-program.html

[3] Emission Facts: Greenhouse Gas Emissions from a Typical passenger Vehicle. US EPA. Overview: Pollutants and Programs. Febuary 2005. Available from http://www.epa.gov/otaq/climate/420f05004.htm#step2

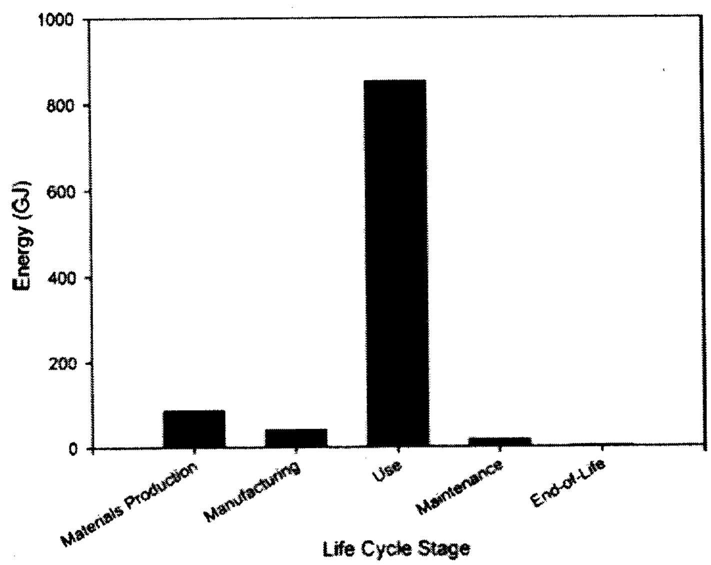
[4] The DOT finds that the avg mpg for the clunker and new vehicle to be 15.8 and 24.9 respectively. Cash for Clunkers Wraps up with Nearly 700,000 car sales and increased fuel efficiency, U.S. Transportation Secretary LaHood declares program "wildly successful." Department of Transportation. [Updated August 26, 2009; Cited Febuary 25 2010]. Available from http://www.dot.gov/affairs/2009/dot13309.htm

[5] Emission Facts: Greenhouse Gas Emissions from a Typical passenger Vehicle. Febuary 2005.

small proportion of the life cycle energy use of the vehicle. Figure 3.1 shows what a small proportion of energy is represented by the end life of a vehicle. Unlike household appliances the energy needed to manufacture a vehicle is substantial. However, the energy needed for material production and manufacturing are not included in this study and are left for further research.

Figure 3.1

Lifetime Energy Use of Vehicles[6]



This scenario assumes that 100% of the people who are taking advantage of Cash-for-clunkers are purchasing their new vehicles solely due to the discount provided by the program.

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[6] Hyung, Chul K., Gregory A. Keoleian, Darby E. Grande, and James C. Bean. 2003. "Life Cycle Optimization of Automobile Replacement: Model and Application." Environmental science & technology 37, no. 23 (12) : 5407-5413.

Calculations

$$\Pr iceperton CO2 = \frac{4215}{\left[\left(\frac{M}{X}\right)-\left(\frac{M}{X1}\right)\right]*Y*.0101}$$

mpg clunker: X
mpg new vehicle: X1
miles driven: M
Additional years the vehicle would have stayed in use: Y
CO2 emitted per gallon = 22.29 pounds
22.29 pounds = .0101 metric tons
$4215 = price per vehicle

Baseline Scenario

This scenario builds on the previous one by incorporating the estimated price elasticity of demand for the US car market based on a study of vehicle purchases made in 1989. The price elasticity of demand (PED) can be used to determine the number of additional cars demanded depending on the change in price. This study, published in 1994, finds the PED of cars to be price inelastic at -.87. [7] This means that the percentage change in cars demanded will be smaller than the percentage change in price. Buying a new vehicle is a large investment and a small change in price does not necessarily make it more affordable to people who were not considering buying a vehicle in the first place. This could be one of the causes of the price inelasticity of vehicle demand.

This scenario begins with the assumption that 100,000 people take advantage of Cash-for-clunkers. This number is used to make calculations easier, but could be replaced with any figure. By using the PED of -.87 and taking into account the parameters of the

[7] McCarthy, Patrick S. 1996. "Market Price and Income Elasticities of New Vehicle Demands." Review of Economics & Statistics 78, no. 3 (08) : 543-547.

first study this scenario results in a price of \$370.26 to avoid the release of 1 ton of CO2 into the atmosphere. This price assumes that the clunker vehicle would have stayed on the road for an additional 4 years. Changing this number to 3 or 5 years results in prices of \$382.56 and \$358.72 respectively.

Calculations

Additional demand created by program = $100000\frac{(-.87*-15)}{100} = 13050$ vehicles

Remaining vehicles in program = $100000 - 13050 = 86950$ vehicles

Total price of program = $\$4215 * 100000 = \$421500000$

$$A = \left[\left(\frac{M}{X}\right) - \left(\frac{M}{X1}\right)\right] * Y * .0101$$

$$B = \left[\left(\frac{M}{x}\right) - \left(\frac{M}{X1}\right)\right] * Y_1 * .0101$$

$$\Pr icepertonCO2 = \frac{421500000}{13050A + 86950B}$$

$$\Pr icepertonCO2 = \frac{421500000}{13050\left[\left(\left(\frac{M}{X}\right) - \left(\frac{M}{X1}\right)\right) * Y * .0101\right] + 86950\left[\left(\left(\frac{M}{x}\right) - \left(\frac{M}{X1}\right)\right) * Y_1 * .0101\right]}$$

A = CO2 saved from new car demand
B = CO2 saved due to increase in efficiency of new car compared to 2009 average
Mpg clunker = X
Mpg new vehicle = X1
Mpg 2009 average vehicle = x
Additional years the clunker would have stayed in use: Y
Life span of new car = Y_1
CO2 emitted per gallon = 22.29 pounds
22.29 pounds = .0101 metric tons
\$4215 = price per vehicle

The PED allows one to find the additional demand created by the decrease in price of a product. In this case the price is, on average, reduced by 15%. According to the National Automobile Dealers Association the price of the average new car in 2006 was $28400.[8] The average Cash-for-clunkers rebate of $4215 represents 15% of this price. To find the additional demand created by this discount simply multiply 15% by -.87 ignoring the negative. This results in an additional demand of 13.05%, which signifies that of the 100,000 people participating in Cash-for-clunkers only 13,050, 13.05% of 100,000, are doing so solely due to the rebate. Now, by using the gallons of fuel saved and the 4-year life span that scenario 1 uses one can determine the total tons of CO2 avoided to be 11.23 tons per vehicle. Multiplying 13050 vehicles by 11.23 tons of CO2 results in 146,551.5 tons of CO2 saved.

The remaining 86950 vehicles that were going to be bought even without Cash-for-clunkers are also saving fuel. According to the EPA the average new 2009 vehicle in the US gets 21.1 mpg; therefore the new vehicles bought in the program are saving an average of 3.8 mpg, or 24.9mpg-21.1mpg. To find the number of gallons saved per vehicle divide the annual vehicle miles of 12000 by 21.1mpg and 24.9 mpg. Then subtract the two numbers to find the number of gallons saved. In this case Cash-for-clunkers is saving 86.80 gallons or .88 tons of CO2 per year. According to the Department of Transportation (DOT) the average lifespan of a vehicle is 13 years.[9] This results in savings of 11.41 tons of CO2 per vehicle. Multiplying these savings by 86,950

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[8] Buying a new Car. Facts for Consumers. Federal Trade Commission. [Updated April 2006, Cited Jan 27 2010] Available from http://www.ftc.gov/bcp/edu/pubs/consumer/autos/aut11.shtm

[9] The Average life span of a vehicle is just over 13 years. US Department of Transportation. [Cited Feb. 24 2010]. Available from http://www.dot.gov/

vehicles yields 992,099.5 tons of CO2 avoided. In order to find the price of the program multiply 100,000 cars by $4215 resulting in $421,500,000. The total tons of CO2 avoided are 146,551.5 + 992,099.5 = 1,138,651 tons. Dividing the price of the program by total tons of CO2 results in the government paying $370.26 to avoid releasing one ton of CO2 into the atmosphere.

Scenario 2

This scenario analyzes Cash-for-clunkers using similar parameters to the previous scenario. It once again assumes the clunker would have survived for another 4 years and the PED is equal to -.87. However, this scenario includes the "rebound effect" of increased fuel efficiency. The rebound effect occurs because as the energy efficiency of the vehicle improves, driving becomes cheaper creating an incentive to drive more. In their study "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect," Small and Dender analyze the rebound effect of fuel efficiency using a pooled cross section of US states for 1966-2001. For the entire data set they find the short and long run rebound effects to be 4.5% and 22.2% respectively. For the years 1997-2001 their values were 2.2% and 10.7%. Small and Dender explain that the rebound has become smaller in recent years due to rising incomes, which make fuel price relatively cheaper.[10] For example, if a consumer has a relatively high income compared to fuel prices then paying for gas is not a large burden. Therefore he or she will already be driving at almost the maximum desired amount. If that consumer switches to a more efficient vehicle then he

[10] Small, Kenneth A., Kurt Van Dender. 2007. "Fuel Efficiency and Motor Vehicle Travel: The Declining Rebound Effect." Energy Journal 28, no. 1 (01) : 25-51.

or she will not necessarily drive more. However, if fuel prices are high compared to income then the rebound will be more pronounced when the consumer makes the switch.

This scenario uses the 10.7% value for the rebound, because the more recent years 1997-2001 will most likely better reflect the current financial situation. Including the rebound effect results in the government paying $414.62 to prevent 1 ton of CO2 from being released into the atmosphere. Changing the number of years the clunker would have survived to 3 or 5 years changes the cost per ton of CO2 to $428.40 and $401.70 respectively.

Calculations

Mpg clunker = X
Mpg new vehicle = X1
Mpg 2009 average vehicle = x
Additional years the vehicle would have stayed in use: Y
CO2 emitted per gallon = 22.29 pounds
22.29 pounds = .0101 metric tons
$4215 = price per vehicle

$M_C = 12000$

$$\mathbf{M_N} = M_C + \left[\left(\left(\frac{X1 - X}{X}\right) * .107\right) * M_C\right]$$

$$\mathbf{M_{N1}} = M_C + \left[\left(\left(\frac{x - X}{X}\right) * .107\right) * M_C\right]$$

$$\Pr icepertonCO2 = \frac{421500000}{13050\left[\left(\left(\frac{M_C}{X}\right) - \left(\frac{M_N}{X1}\right)\right) * Y * .0101\right] + 86950\left[\left(\left(\frac{M_C}{x}\right) - \left(\frac{M_{N1}}{X1}\right)\right) * Y * .0101\right]}$$

The new prices that include the rebound effect are higher due to an increase in annual vehicle miles for the new vehicle. Once again according to the DOT the average clunker used 15.8 mpg, while the average new vehicle in the program uses 24.9 mpg. The difference in these two vehicles is the equivalent to a 58% improvement in efficiency. To find the increase in annual miles take the .58 improvement in fuel efficiency and multiply it by the estimated rebound of .107, which yields .062. Multiplying .062 by the original 12,000 annual miles that the clunker vehicle is driven results in the new car being driven an additional 739.52 miles, for a total of 12,739.52 miles. Since the new car is driven further, less CO_2 is saved. The mileage for the vehicles that are not purchased solely due to the program also changes because of the rebound effect. The average new vehicle in 2009 gets 21.1 mpg while the new vehicles under Cash-for-clunkers get an average of 24.9 mpg. Take the .18 improvement, multiply it by .107 and get .02. This results in the new vehicles driving 231.24 additional miles for a total of 12,231.24 annual vehicle miles. Now applying the increased annual vehicle miles to the equation presented in the previous scenario yields a price of $414.62 for a one-ton reduction in CO_2 emissions.

Summary

Although Cash-for-clunkers may have been an effective stimulus program, calculations seem to indicate that it was an expensive way of reducing CO_2 emissions. The baseline scenario results in a price of $370.26 per ton of CO_2 and when the rebound effect is included this number increases to $414.62. These scenarios are based off of a market PED calculated from 1989 data. This PED is old and could be inaccurate, but the PED is not varied due to the fact that changing it does not significantly alter the scenario. These scenarios do not take into account the fact that the people who were intending to buy a new vehicle even without the program would not have recycled their old vehicle without the cash incentive. They would have resold the old vehicle or kept it as a backup.

This information is not included, because of the difficulty of calculating the annual vehicle miles the old vehicle would be driven. Even though this seems to indicate a potential better outcome for the scenario, taking into account the average annual vehicle miles for the clunker based on age would most likely result in a higher price per ton of CO2. Allan, Carpenter, and Morrison in their article "Abating Greenhouse Gas Emissions through Cash for Clunker Programs" include the fact that average annual vehicle miles traveled decreases as a vehicle ages. This study could indicate that the vehicles replaced were not primary vehicles to begin with and would not have been driven 12000 miles annually as indicated in the above scenarios. [11]

[11] Allan, Alexander, Rachel Carpenter, and Geoff Morrison., 2009. "Abating Greenhouse Gas Emissions through Cash-for-Clunker Programs." Transportation Technology and Policy Group, Department of Civil and Environmental Engineering. University of California Davis.

Figure 3.2[12]

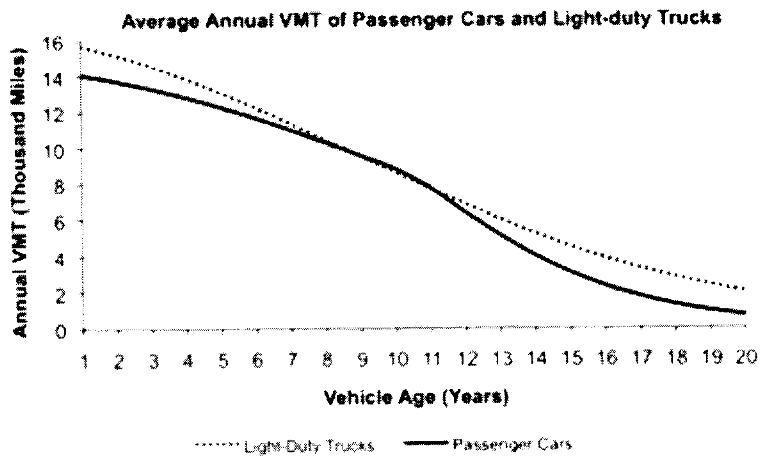

Figure 3.2 demonstrates that there is a significant drop in annual vehicle miles per year when a car becomes 12-14 years old. The average Cash-for-clunkers vehicle was between 13 and 14 years old, which indicates that it would not have been driven nearly 12000 miles per year.[13] Additional research is needed to create a scenario that takes into account the change in vehicle miles traveled due to age, but it would most likely yield a much higher price for reducing CO2 emissions.

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[12] Ibid

[13] Knittel, Christopher R. "Implied Cost Clunkers" 2009.

CHAPTER IV

CASH FOR CLOTHES WASHERS

This chapter analyzes a Cash-for-clothes washers government program using several different scenarios. Scenario 1 assumes that 100% of individuals taking advantage of the program will have done so solely due to the program. The next scenarios use price elasticity of demand and various additional changes to the program to make it more realistic. In these scenarios unless otherwise noted certain parameters are kept constant such as the average price of a new energy star washing machine at $750 and a government rebate of 20%.[1] According to the US Bureau of Economic Analysis (BEA) household appliances depreciate in value at approximately 15% per year.[2] This indicates that after ten years a clothes washer bought for $750 will be worth $147.66. The 20% rebate is reasonable because it results in the government paying $150 per trade in unit. The cost of disposal of these old appliances is not included in this analysis. However 85-90% of all clothes washers, refrigerators, dishwashers, etc. are recycled and require between 1.25 and 1.75 kWh to shred.[3] These energy values are so low that they are not included in the analysis. Energy savings per unit for the first scenario is 2233 kilowatt

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[1] Energy Star. "Clothes Washers Qualified Products." EPA and DOE, [Updated 2009; Cited November 2010]. Available from http://www.energystar.gov/index.cfm?c=clotheswash.pr_clothes_washers

[2] BEA Depreciation Estimates. Bureau of Economic Analysis. Available from http://www.bea.gov/national/FA2004/Tablecandtext.pdf

[3] Bole, Richard. "Optimization Clothes Washer" 2006.

hours (kWh), which means that the energy needed to scrap the appliance accounts for (1.5/2233)*100 or .067% of the total. This seems to indicate that the disposal cost would be low and more or less limited to transportation costs, which are not included in this study.

Scenario 1

Scenario 1 assumes that 100% of individuals that take part in the program are replacing their clothes washer solely due to the government rebate program. Under this assumption and with other parameters discussed in this study the government would be paying between $112.28 and $224.55 to avoid releasing one metric ton of CO2 into the atmosphere. These calculations are relatively simple to understand. The Association of Home Appliance Manufactures (AHAM) provides the amount of energy use per washing cycle for the average clothes washer based on model year (MY). Assuming that the average American household does 400 loads of laundry a year the average energy use for MY 1996-2000 per year is 744 kWh.[4] According to the US Department of Energy (DOE) the average life of a typical clothes washer is 14 years.[5] Therefore it is reasonable to assume that many appliances from these model years and older are still in use. The average Energy Star qualified washing machine today uses only 185 kWh hours per year,

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[4] AHAM. Clothes Washers Energy Efficiency and Consumption Trends. Association of Home Appliance Manufacturers. June 1, 2005.

[5] Young, Denise. 2008. "When do energy-efficient appliances generate energy savings? Some evidence from Canada." Energy Policy 36, no. 1 (01) : 34-46.

less than a third of the older top-loading machines.[6] Changing to an Energy Star washing machine could save an average of 558.25 kWh of energy per year.

In order to estimate total energy savings the model needs the average number of years that the old clothes washer would have survived. This scenario uses 4 years for the estimated additional lifespan of the old clothes washer. This number is the estimated additional years that a 10-year-old machine will survive based on the 14-year lifespan from the DOE. Machines that are older than 10 may not survive for this long, but as a machine grows older the probability that it will survive for longer than the estimated 14 year life span increases. Now total energy savings equal 558.25* 4, or 2233 kWh per new appliance. Using the Greenhouse gas protocol Initiatives CO2 emissions calculator 2233 kWh would result in 1.336 metric tons of CO2 saved per new clothes washer.[7] Assuming the average price of a new energy star clothes washer is $750 and there is a 20% discount then the government would be paying $150 per unit sold. Divide $150 by 1.336 metric tons of CO2 and the government would be paying $112.28 per ton.

Calculations

$$\text{Price per ton } CO_2 = \frac{xp}{f[(e - e_1)y]}$$

Where f is a function that converts electricity into tons of CO2 using the Green House Gas Protocol Initiative Calculator

p = Appliance price

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[6] Energy Star. "Clothes Washers Qualified Products." 2009

[7] The Greenhouse Gas Protocol Initiative. Calculation Tools. [Cited Feb 23 2010]. Available from http://www.ghgprotocol.org/

x = % Government Discount
e = Initial energy use
e_1 = Energy star energy use
y = Years

Or

$$\$112.28 = \frac{.20 * 750}{f\left[(744 - 185)4\right]}$$

The higher estimate of \$224.55 per ton of CO_2 is achieved by changing the life expectancy of the old appliance to 2 rather than 4 years. This is done due to the chance of clothes washers older than MY 2000 not surviving past the expected 14-year life span. Therefore the scenario uses 2 years to show the upper estimates of the model. The real number would probably lie closer to the lower estimate considering the increasing likelihood of an older appliance to survive past the expected life span. Also no estimates were found that addressed the decrease in efficiency over time for clothes washers. This could mean that energy use for the oldest appliances would be much higher resulting in larger energy savings when changing to a more modern machine.

Baseline Scenario

This baseline scenario uses the same quantities for energy use of the old and new appliance, but also includes the price elasticity of demand (PED) for clothes washers. The PED is used to estimate the additional demand for a product due to an increase or a decrease in price. The problem with clothes washers is that they are not generally considered aesthetically pleasing products or have any other value accept for their function to clean clothes. Therefore small changes in price are not likely to increase demand dramatically. This generalization coincides with the 2008 Berkeley study of the

Price Elasticity of Demand of Household Products, which determines that the PED for household appliances is price inelastic.[8]

To make calculations simple this scenario assumes that 100,000 clothes washers are sold under the government program. Once again this is an arbitrary number that is simply used to make calculations easier. According to the price elasticity of demand study the PED for clothes washers based on data from 1980-2002 falls in the range of -0.26 to -0.31.[9] Taking into account this PED the model calculates that the government would be paying between \$780.82 and \$734.68 for a one-ton reduction of CO2 emissions.

Calculations

Additional demand due to program = $100000\frac{(-.31*-20)}{100}=6200$

Individuals that switched to Energy Star due to program = 93800-93800z

Or

93800-93800(.72) = 26264

Total price of program = 15000000 = 100000 * 150

$$A = f\left[(e - e_1)y\right]$$

$$B = f\left[(e_c - e_1)y_1\right]$$

[8] Dale, Larry. 2008. "An Analysis of the Price Elasticity of Demand for Household Appliances." 2008. eScholarship. Lawrence Berkeley National Laboratory. Available from http://escholarship.org/usc/item/5qr2f2nz.

[9] ibid

$$\Pr icepertonCO_2 = \frac{15000000}{6200A + 26264B}$$

Or

$$\Pr icepertonCO_2 = \frac{15000000}{6200f\left[(e - e_1)y\right] + 26264f\left[(e_c - e_1)y_1\right]}$$

Where f is a function that converts electricity into tons of CO2 using the Green House Gas Protocol Initiative Calculator
A = CO2 savings from additional demand
B = CO2 savings from switching to Energy Star vs. Conventional model
z = Market Penetration
p = Appliance price
x = % Government Discount
e = Initial energy use
e_1 = Energy star energy use
e_c = Conventional energy use
y = Additional years use for old washer
y_1 = Average life span of washer

The PED allows one to calculate the percent of additional demand created by a given discount on the price of a product. In these models clothes washers are discounted 20%. To find the additional demand created by the discount multiply -.31 by 20%. In this case the negative sign is ignored and the problem yields an additional demand of 6.2%. Taking 6.2% of 100,000 units results in 6200 additional units sold due to the decrease in price. The total CO2 reduction for one unit, calculated in the previous scenario, is 1.336 tons. This estimate uses 4 years as the additional predicted life span of the clothes washer. The resulting CO2 reduction would be 6200*1.336 or 8283.2 tons of CO2.

The 93,800 units remaining represent people who are taking advantage of the program, but would have bought new machines even if the government rebate did not exist. In the year 2006 Energy Star washing machines enjoyed 72% market penetration.[10]

[10] Energy Star. "Clothes Washers Qualified Products." 2009.

This means that 72% of 93800 units or 67536 of the remaining units would have changed to Energy Star Clothes washers during the program even without its existence. However, the remaining 28%, or 26,264 units, changed from conventional clothes washers to energy star rated machines because of the program. This results in additional CO2 savings. Energy star clothes washers are a minimum of 30% more energy efficient than conventional machines.[11] Therefore if the average energy star clothes washer uses 185.75 kWh per year, the lower estimates of energy savings would be 55.73 kWh per year. Once again using the same green house gas calculator this would amount to .033 tons of CO2 per year. Assuming that the machine would be used for the full 14 years, estimated by the DOE, the total savings would be .462 tons of CO2 per unit. This results in 26,264 units * .462, which equals a reduction of 12,133.97 tons of CO2. Add the two numbers together and the total CO2 reduction comes to 20,417.17 tons.

After arriving at this conclusion, calculating the price per ton is a simple matter of multiplying 100,000 units by $150 (average discount), which comes to $15 million. Then divide the $15 million by the CO2 saved, which results in the government paying $734.68 to reduce CO2 emissions by 1 ton.

The higher price for reducing CO2 is found by using a different PED. The study "An Analysis of the Price Elasticity of Demand for Household Appliances" finds a low and a high estimate. The preferred estimate uses a simple regression to find a PED of -.31. The scenario also provides the lower estimate of -.26, which results in the higher price of $780.82 per ton. This study contains the most relevant and recent data concerning the Price Elasticity of Demand of household appliances although it only used data from 1980 through 2002. The PED is determined to be very inelastic, because most

[11] ibid

of the demand is created by household starts, and replacement of existing appliances. By including the additional demand created by a government rebate the model becomes more realistic and indicates that Cash-for-clothes washers may not be a cost efficient environmental program.

Scenario 2

Although historically the PED for household appliances has been very inelastic it is also interesting to examine the impacts of the government program with the possibly unrealistic assumption that clothes washers are an elastic good. This scenario will assume that instead of clothes washers having an inelastic PED of between -.26 and -.31, they will instead have an elastic PED value of -1 and -1.5. These two PED values would result in additional demand created by the program as 20% and 30% respectively. Although this scenario is unrealistic, it is interesting due to the large scale of the program, and the country's changing consumer preferences towards environmentally friendly products. Also Cash-for-clunkers was a very popular government program and therefore a similar program has the potential to share some of that popularity. These points cannot be quantified into any sort of exact increase in demand for household appliances, but this observation makes analyzing a scenario with a higher PED more applicable.

In this case one would use the same calculations that are demonstrated above, but use -1 and -1.5 for the PED. This calculation results in the government paying $404.65 and $305.28 per ton for -1, and -1.5 respectively, which is half of the price of the baseline scenario. This additional analysis demonstrates the potential benefits of publicity and increasing public awareness of the inefficiency of older appliances.

Scenario 3

It is also interesting to analyze how changing the government rebate to 15% or 30% effects the baseline scenario. If the rebate is changed to 15% then the scenario results in a cheaper price of $606.57 for a one-ton reduction in CO_2. A rebate of 30% yields a price of $931.40 per ton. The rebate of 15% is not higher than the resale value of the appliance according to the BEA, but may still be an effective discount, because many people will be willing to accept the lower trade-in price in exchange for the convenience of a reliable price offered from the government. Increasing the rebate only makes the scenario worse due to an inelastic PED.

Summary

This analysis results in a baseline scenario that demonstrates that a Cash-for-clothes washer style program is an expensive way to reduce CO_2 emissions. The price of $734.68 to avoid 1 ton of CO_2 is much more expensive than Cash-for-clunkers. However if the program enjoys a more elastic PED then the program becomes much less expensive. These scenarios could be improved by including information concerning the loss of efficiency over time, but this analysis is left for future research.

CHAPTER V

CASH FOR REFRIGERATORS

This chapter, similar to the clothes washer chapter, analyzes a Cash-for-refrigerators government program using several different scenarios. Scenario 1 assumes that 100% of individuals taking advantage of the program will have done so solely due to the program. The next scenarios use price elasticity of demand and various other factors to make the outcomes more realistic. Certain conditions are kept constant unless otherwise noted. The DOE estimates the average lifespan of a refrigerator at 19 years. [1] The average price of a new refrigerator is $1180 and the government discount will be 20%.[2] The 20% discount ensures that the rebate is higher than the resale value of the appliance based on the Bureau of Economic Analysis' estimated depreciation rate of 15%.[3] The cost of manufacturing and disposal of the refrigerators is not taken into account. Figure 4.1 demonstrates that the small fraction of energy from the construction and recycling of the appliance does not make a significant difference when analyzing lifetime energy use. Keep in mind that the use phase in figure 4.1 shows only the energy

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[1] Young, Denise. 2008. "When do energy-efficient appliances generate energy savings? Some evidence from Canada." Energy Policy 36, no. 1 (01) : 34-46.

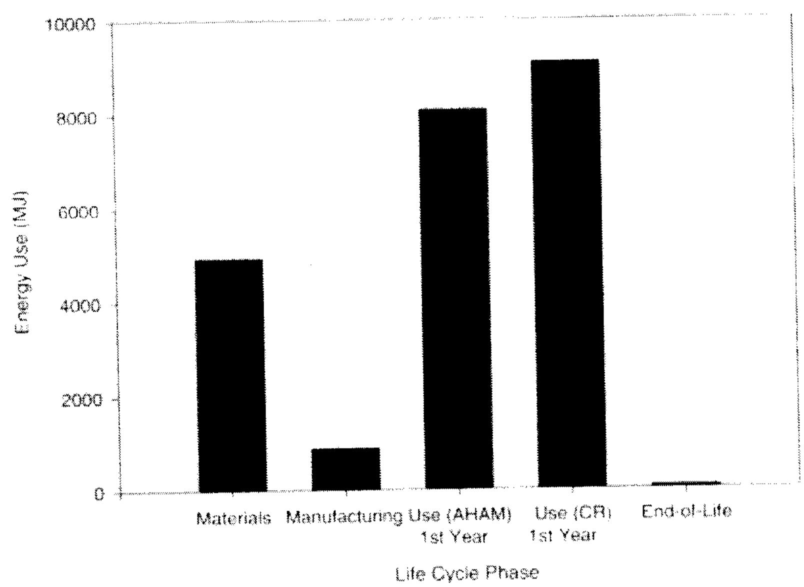
[2] Energy Star. "Refrigerator Qualified Products." EPA and DOE, [Updated 2009; Cited November 2010]. Available from http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=F

[3] BEA Depreciation Estimates. Bureau of Economic Analysis. Available from http://www.bea.gov/national/FA2004/Tablecandtext.pdf

use for 1 year, which will need to be multiplied by 19 years to represent a more realistic lifetime energy use.

Figure 5.1

Life Cycle Energy Use of Average Refrigerator[4]



Scenario 1

This first scenario, like the scenario for clothes washers, will also assume that 100% of people taking advantage of the rebate have decided to purchase a new refrigerator solely because of the program. To participate, people will have to be currently using a refrigerator that is from the year 2000 or older. This assumption results in the government paying $103.20 for a one metric ton reduction in CO2 emissions. If the number of years that the refrigerator would have survived is decreased to 4.5 years then

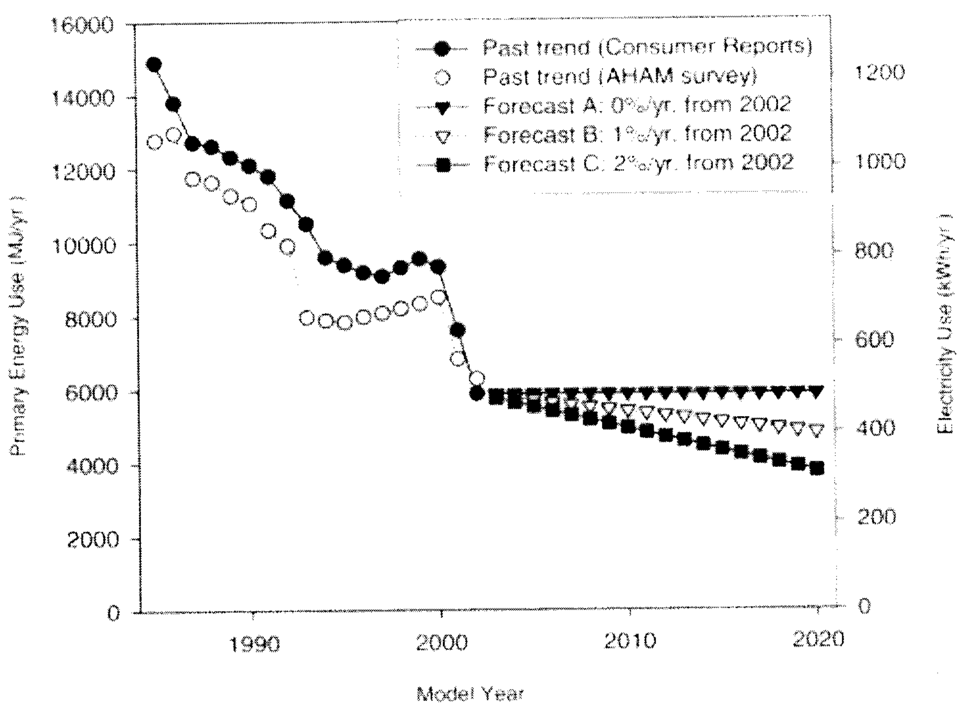
[4] Kim, Hyung C., Gregory A. Keoleian, and Yuhta A. Horie. "Optimal Refrigerator" 2006.

this number becomes $217.23. This number shows the upper estimates of the model taking into account that many refrigerators may not survive the additional 9 years.

To achieve the original price of $103.20 the scenario begins with the approximate energy use of 770 kWh.[5] This value is the average estimated energy use of Model Years 1995 through 2000 based on Figure 4.2. Kim, Keolian, and Horie write that the higher consumer report values are probably more accurate than the American Home Appliance Manufacturers (AHAM) survey. Therefore the scenario uses the consumer report values to achieve the 770 kWh estimate.

Figure 5.2

Refrigerator Energy Use (AHAM)[6]



[5] ibid

[6] ibid

Using data from an empirical study, Johnson estimates that fridges over 10 years old are 21% less efficient due to deterioration of insulation.[7] The deterioration of other components also contributes to decreasing efficiency, but are not well studied and are therefore not included in the analysis. Taking into account the loss of efficiency of the old refrigerators increases the energy use to an average of 931.7 kWh per year. The average efficiency of an energy star fridge is 461.9 kWh per year, resulting in 469.8 kWh being saved per year that the old fridge would have been in use. Assuming an additional lifespan of 9 years (based on DOE 19 year life estimate) the total energy saved per unit would be 4157.1 kWh or a 2.529-ton CO2 reduction. The average price of a new refrigerator is $1180 and the government would provide a 20% rebate resulting in a price of $236 per unit. Additionally the government would need to pay a $25 disposal fee for the Freon or similar substance in the old refrigerator.[8] Dividing the new cost of $261, that includes the disposal fee, by 2.529 tons, results in a price of $103.21 for a one metric ton reduction in CO2 emissions.

Calculations

$$\text{Pr}\,icepertonCO_2 = \frac{xp}{f\left[\left(.21e - e_1\right)y\right]}$$

Where f is a function that converts electricity into tons of CO2 using the Green House Gas Protocol Initiative Calculator
p = Appliance price

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7 Johnson, R. W., 2000. The effect of blowing agent on refrigerator/freezer TEWI. Polyurethanes Conference 2000, Boston, MA.

8 Kim, Hyung C., Gregory A. Keoleian, and Yuhta A. Horie. 2006. "Optimal household refrigerator replacement policy for life cycle energy, greenhouse gas emissions, and cost." Energy Policy 34, no. 15 (10) : 2310-2323.

x = % Government Discount
e = Initial energy use
.21 = loss in efficiency
e_1 = Energy star energy use
y = Years

Baseline Scenario

Similar to the clothes washer scenario the model for refrigerators also uses the Price Elasticity of Demand (PED) from the Berkeley study in order to achieve a more realistic result of the demand created by the program. The study found that in the period of 1980 – 2002 refrigerators had a PED of between -.4 and -.34.[9] Using the data from the previous preliminary scenario the two different PEDs result in a price of $302.03 and $309.82 to avoid the release of 1 ton of CO2 respectively.

Calculations

Additional demand due to program = $100000\frac{(-.4*-20)}{100} = 8000$

Individuals that switched to Energy Star due to program = 92000-92000z

Or

94800-94800(.3116) = 63332.8

Total price of program = 100000*261 = 26100000

$$A = f\left[(.21e - e_1)y\right]$$

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[9] Dale, Larry. 2008. "An Analysis of the Price Elasticity of Demand for Household Appliances." 2008. eScholarship. Lawrence Berkeley National Laboratory. Available from http://escholarship.org/usc/item/5qr2f2nz.

$$B = f\left[(e_c - e_1)y_1\right]$$

$$\Pr icepertonCO_2 = \frac{26100000}{8000A + 63332.8B}$$

Or

$$\Pr icepertonCO_2 = \frac{26100000}{8000f\left[(.21e - e_1)y\right] + 63332.8f\left[(e_c - e_1)y_1\right]}$$

Where f is a function that converts electricity into tons of CO2 using the Green House Gas Protocol Initiative Calculator
A = Energy saved due to new demand
B = Energy saved due to increased energy star market penetration
z = Market Penetration
p = Appliance price
x = % Government Discount
e = Initial energy use
.21 = loss of efficiency
e_1 = Energy star energy use
y = Additional years for old fridge
y_1 = life span of new fridge

This scenario starts with the assumption that 100,000 people are taking advantage of the program. Multiplying the government discount by the first PED of -.4 results in only 8000 people replacing their refrigerator solely due to the program. Taking this number and multiplying it by the CO2 avoided for 1 unit calculated in scenario 1 results in a reduction of 20,232 tons of CO2. Additionally, for the rest of the people taking advantage of the rebate some are switching from purchasing conventional refrigerators to energy star rated fridges solely because of the program. These people are reducing CO2 emissions as well. Based on data from 2006 energy star refrigerators have 31.16% market penetration.[10] Therefore the remaining 68.84% of people using the program are changing to energy star fridges solely due to the program. Energy star fridges are a minimum of 20% more efficient than new conventional fridges. To find the improvement in efficiency take the energy star energy use of 461.9 kWh and increase it by 20%. Then subtract this number from the original 461.9 kWh. Multiply the improvement by the average lifespan of 19 years. The final step is to multiply the energy savings from the single unit by the 63,332.8 new units in the study. This results in energy savings equivalent to 66,182.8 tons of CO2. Adding the CO2 savings from the previous equation results in a total of 86,414.77 tons of CO2. To find the total cost of this reduction take the government price per unit of $261 and multiply it by 100,000 units, yielding $26,100,000. Then take the total price and divide it by 86,414.77 tons of CO2. This results in the government paying $302.03 to avoid the release of one ton of CO2 in the atmosphere.

Scenario 2

Although refrigerators like clothes washers have historically had a low PED, it is interesting to examine the scenario assuming an elastic PED. This scenario will use the same PED of -1 and -1.5 as the clothes washer analysis. With the 20% government rebate the PED of -1 results in an additional demand of 20%, while the PED of -1.5 results in an additional demand of 30%. Using the same calculations that were used in the baseline scenario yields a price of $241.38 and $206.77 for -1 and -1.5 respectively. This scenario

[10] Energy Star. "Refrigerator Qualified Products." EPA and DOE, [Updated 2009; Cited November 2010]. Available from http://www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=F

although it does not have a PED supported by research is of interest due to the publicity and public support that will accompany a large-scale government program.

Scenario 3

It is also interesting to examine the effectiveness of a government program that offers a government rebate that is higher or lower than the 20% discount used in the baseline scenario. Using the same methodology and changing the rebate to 15% or 30% results in the government paying $244 or $404.70 per ton of CO2 for 15% and 30% respectively. This is relevant, because in certain cases refrigerators that are 10 years old may have a higher or lower resale value than the 20% government rebate.

Summary

The Cash-for-refrigerators program in the baseline scenario results in the government paying $302.03 to avoid releasing 1 ton of CO2 into the atmosphere. This is lower than the estimates for both clothes washer and cars, which cost $780.82 and $370.26 respectively. The refrigerator scenarios could be improved by including more data on loss of efficiency over time for both the old and new refrigerator, but this analysis is left for additional research.

CHAPTER VI

CONCLUSION

The goal of this study is to determine how effective the Cash-for-clunkers vehicle scrappage program was in its goal of reducing CO_2 emissions. Additionally, it compares the Cash-for-clunkers program to a similar rebate system for refrigerators and clothes washers in order to determine their relative cost efficiency. The baseline scenarios for the three products show that refrigerators are the least expensive system with the government paying approximately $302.03 for a one metric ton reduction in CO_2. Cash-for-clunkers comes in second with a price of $370.26 or $414.62 per ton including the rebound effect, and clothes washers is more expensive with a price of $734.68 per metric ton of CO_2. The base results for each of the scenarios are summarized in figure 5.1.

Table 6.1

Scenario Prices

Program	100% New Demand	Baseline (PED)	PED -1	PED -1.5	15% Rebate	30% Rebate	Rebound Effect
Vehicles	$375.50	$370.26	N/A	N/A	N/A	N/A	$414.62
Clothes Washers	$112.28	$734.68	$404.65	$305.28	$606.57	$931.40	N/A
Refrigerators	$103.20	$302.03	$241.38	$206.77	$244	$404.7	N/A

When examining the three programs under the assumption that all the individuals taking advantage of the program are doing so solely due to the rebate system, refrigerators and clothes washers are the clear winners. The price of the CO2 reduction per metric ton for refrigerators and clothes washers results in $103.20 and $112.28 respectively. Cash-for-clunkers comes in a distant last place with a price of $375.50. However, when the Price Elasticity of Demand is included the Cash-for-clunkers scenario improves while the scenarios for clothes washers and refrigerators worsen considerably. The PED for all the scenarios is inelastic, which explains why the results for Clothes Washers and Refrigerators are much worse. In the case of Cash-for-clunkers the vehicles that would have been purchased even without the program had a much higher average mpg then if the program did not exist. In order to qualify for Cash-for-clunkers consumers had to buy vehicles that were considerably more fuel-efficient than the trade-in vehicle. The average new vehicle mpg in 2009 was 21.1[1] while the average mpg for the new vehicles under the Cash-for-clunkers program was 24.9.[2] This difference in mpg when multiplied by the full 13-year lifespan of the vehicle accounts for greater CO2 savings than the savings due to the retirement of the clunker vehicle. Therefore in this case a more inelastic PED results in greater CO2 savings. However, the difference is very

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[1] Emission Facts: Greenhouse Gas Emissions from a Typical passenger Vehicle. US EPA. Overview: Pollutants and Programs. Febuary 2005. Available from http://www.epa.gov/otaq/climate/420f05004.htm#step2

[2] Cash for Clunkers Wraps up with Nearly 700,000 car sales and increased fuel efficiency, U.S. Transportation Secretary LaHood declares program "wildly successful." Department of Transportation. [Updated August 26, 2009; Cited Febuary 25 2010]. Available from http://www.dot.gov/affairs/2009/dot13309.htm

small which signifies that changing the price elasticity of demand for the car market does not significantly change the outcome.

The next two scenarios examine a situation where the PED for clothes washers and refrigerators is elastic. Changing the PED for cash for clunkers, as explained in the previous paragraph, does not change the outcome significantly and is therefore not included in the analysis. Changing the PED for Clothes Washers to -1 or -1.5 results in values of $404.65 and $305.28 respectively. Doing the same for refrigerators results in $241.38 and $206.77. These scenarios are interesting, because the additional publicity from a widespread government program could result in an additional increase in new demand, which in turn could reduce the cost of retiring carbon.

The last scenario for Cash-for-clunkers includes the rebound effect, and results in a higher price per ton of CO2. Vehicles that use less fuel are generally driven more therefore it is realistic to assume that the new vehicle will be used more frequently than the clunker. Including the rebound effect results in the higher price of $414.62 per metric ton of CO2.

All three scenarios demonstrate rebate systems that are relatively inefficient at reducing CO2 emissions. Among the three products the refrigerator rebate system would be the most effective requiring approximately 70 less dollars per metric ton than Cash-for-clunkers. However, additional research may find that the price difference between the programs would be far greater. The Cash-for-clunkers scenario does not include the change in annual miles of a vehicle due to age. Adding this variable would most likely result in a far higher price for CO2. Also, publicity for the appliance rebate systems has the potential to significantly improve those scenarios, as demonstrated in the PED -1, and

-1.5 scenarios. Additionally, it is easier to estimate how frequently a refrigerator is used compared to a vehicle. Therefore, a refrigerator rebate system would seem to be a more effective and easily measurable choice for a program to reduce CO_2 emissions.

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