Impacts of Fleet Turnover Strategies on Passenger Vehicle Use and Greenhouse Gas Emissions

Technical Background Document

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Study Selection

In recent years, a number of studies have evaluated the CO_2 effects of government incentive programs aimed at improving the fuel efficiency of the passenger vehicle fleet, including incentives for vehicle scrappage and for purchase of hybrid and alternative fuel vehicles. The four studies from which effect sizes are reported in the policy brief use data collected on programs implemented in North America and estimate the magnitude of the effect on the vehicle fleet, reductions in greenhouse gas (GHG) emissions, and/or the cost-effectiveness of GHG emissions reductions (Chandra et al., 2010; Beresteanu and Li, 2011; Li et al., 2013; Lenski et al., 2013). Three additional studies do not provide estimates of the effect size but provide important insights into effects of incentive programs and thus are discussed below (Diamond, 2009; Gallagher and Muehlegger, 2011; Zolnik, 2012). This review does not include studies that model hypothetical programs (e.g., Train et al., 1997; Greene et al., 2005; Spitzly et al., 2005; BenDor and Ford, 2006), evaluate programs outside of North America, or are not published in a peer reviewed journal.

Effect Size, Methodology, and Applicability Issues

System Effects

Complete assessment of GHG emissions reductions from incentive programs requires accounting for a number of system level effects, both intended (direct) and unintended (indirect) (Sallee, 2010; Van Wee et al., 2011). These effects fall into four major categories: changes in the vehicle fleet, lifetime vehicle miles traveled (VMT), vehicle fuel economy, and lifecycle[1] CO_2 effects from acceleration of the production and manufacturing of new vehicles, and scrapping of old vehicles. Within each category, we note direct program effects in Table 1 and indirect effects in Table 2. The different effects are defined below. Table 3 includes a summary of the direct and indirect effects included in the four studies cited in the policy brief.

The direct effect of programs on the *vehicle fleet, as shown* in Table 1, occurs when the number of fuel-efficient vehicles in the fleet increases relative to less fuel-efficient

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[1] Effects of resource use, including emissions, generated throughout the life of a product.

vehicles. There are, however, uncertainties surrounding what consumers would purchase in the absence of the program. Effects may be over-stated if the program only slightly alters the timing of a decision that would have been made anyway to purchase a fuel-efficient vehicle (indirect *inter-temporal* effect in Table 2) or if the program displaces the purchase of an equally or only slightly more fuel-efficient standard vehicle (indirect *cross-substitution effect* in Table 2). Three of the studies included in the brief captured the inter-temporal effect and the cross-substitution effect (Li et al., 2013; Chandra et al., 2010; Beresteanu and Li, 2011). The evidence indicates that both of these effects are significant and ignoring them tends to over-estimate program effects.

Table 1: Direct Effect of Scrappage in Hybrid Incentive Programs

Outcome	Direct Effects
Vehicle Fleet	Change in number of vehicles by make, model, and year
Vehicle Fleet Fuel-Efficiency	Change in average miles per gallon for vehicle fleet
Vehicle Lifetime and Distance Traveled (Miles)	Change in lifetime of vehicles and distance traveled
Lifecycle CO_2	Increased emissions from acceleration of car production and scrappage

Table 2: Indirect Effect of Scrappage in Hybrid Incentive Programs

Outcome	Indirect Effects
Vehicle Fleet	Inter-temporal: Timing of vehicle purchase accelerates only slightly for vehicle that consumer had already decided to purchase (consequence: CO_2 reductions over-estimated)
	Cross-substitution: Purchased qualifying vehicle but would have purchased an equally or only slightly less fuel-efficient vehicle (consequence: CO_2 reductions over-estimated)
	Spillover: More alternative fuel vehicles are purchased over time without additional incentive programs because consumers see these vehicles in wider use and gain confidence in the new technology (consequence: CO_2 reductions under-estimated)
Vehicle Lifetime and Distance Traveled (Miles)	Rebound: New and more fuel-efficient vehicles may be driven more than current vehicles due to lower operating costs and greater comfort and reliability (consequence: CO_2 reductions over-estimated)
	Self-selection: Program disproportionately attracts vehicles in poorer condition and/or with shorter expected lifetime compared to a typical vehicle in the fleet (consequence: CO_2 reductions over-estimated)

On the other hand, total effects may be under-counted if indirect technology spill-over effects are not considered, that is, more hybrid or plug-in electric vehicles are purchased over time, after the incentive program has ended, because consumers see these vehicles in wider use and gain confidence in the new technology. The literature

provides no evidence for the significance or magnitude of this indirect effect. None of the studies reviewed included this effect.

The direct *vehicle lifetime and distance traveled effect* in Table 1 is the difference in the total time and total distance that the displaced vehicle (old scrapped vehicle) and target vehicle (new fuel-efficient vehicle qualified under the incentive program) will be used. These effects could be over-estimated if the program disproportionately attracts vehicles in poorer condition and/or with shorter expected lifetime relative to typical vehicles in the fleet. This is known as the indirect *self-selection* effect in Table 2. These types of vehicles are likely to be used less over time because of high operating costs (fuel and repairs) and less comfort and reliability.

Two studies included in the review account for the self-selection effect. Lenski et al., (2013) use surveys of participants in the 2009 CARS[2] scrappage program to identify the types of vehicles participants scrapped. However, Zolnick (2012) reports that the CARS survey used by Lenski et al. (2013) was completed by about 22 percent of total program participants and survey responses could not be linked to individual trade-in and purchase data; thus it is unclear how well the sample represents the population of participants. Li et al. (2013) use Lu's (2006) age-survival probabilities based on analyses of the 2001 National Household Transportation Survey (NHTS) data.

New and more fuel-efficient vehicles may be driven more than current vehicles due to lower operating costs and greater comfort and reliability (Hsu and Sperling, 1994; Small and Dender, 2007). This is known as the indirect *rebound effect.* Three studies include and quantify rebound effects in their analysis (Zolnick, 2012; Li et al., 2013; Beresteanu and Li, 2011). The failure to account for this effect will over-estimate total CO_2 reductions.

Another significant source of bias is the over-estimation of vehicle fuel economy ratings compared to actual on-road fuel economy, resulting in an over-estimation of CO_2 emissions savings (Sallee, 2010). A recent report by *Consumer Reports* magazine ("The MPG Gap," August 2013) reports that sticker ratings over-estimate actual use fuel efficiency. They found that "of the hybrids we've recently tested, 55 percent fell short of their EPA [U.S. Environmental Protection Agency] combined city/highway estimates by 10 percent or more." This is due to EPA rating procedures that "are based on outdated

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[2] The Car Allowance Rebate System (CARS) program, implemented by the U.S. Department of Transportation in 2009 for a period of three months, provided a one-time subsidy of $3,500 or $4,500 to dealers for scrapping inefficient vehicles traded-in for new, fuel-efficient vehicles. This $3 billion scrappage program provided subsidies for the purchase of 688,511 fuel efficient vehicles nationwide in 2009, representing less than 1 percent of all registered vehicles (Zolnick, 2012).

tests designed to measure vehicles with conventional powertrains in particular driving situations rather than today's increasingly sophisticated gas/electric systems." As a result, CO_2 benefits of incentive programs, especially those that target hybrid vehicles, are likely over-estimated. None of the studies reviewed accounted for this potential bias.

Scrappage programs are likely to accelerate vehicle production (including the manufacture and transportation of the parts and the finished vehicles). The CO_2 effects of these processes, not just the actual use of the vehicles, should also be considered. However, the data used to develop lifecycle GHG effects are limited, as are the models currently used to represent system dynamics. As a result, there are significant uncertainties associated with these estimates. Only one study accounted for this effect and found that lifecycle effects offset 15 percent of the net direct and indirect CO_2 reductions anticipated if these lifecycle effects were not included in the analysis (Lenski et al., 2013). As a result, the failure to represent this effect may over-estimate the reduction of CO_2 in these programs.

Table 3: Direct and Indirect CO_2 Effects Captured by Study

Study	Study Location	Study Year	Program Type	Direct Effects	Indirect Effects
Beresteanu and Li (2011)	U.S.	2006	Hybrid: income tax credit	Vehicle fleet Fleet fuel efficiency Vehicle lifetime and VMT	Inter-temporal Cross-substitution Rebound
Chandra et al. (2010)	Canada	2001-2006	Hybrid: rebates	Vehicle fleet Fleet fuel efficiency Vehicle lifetime and VMT	Inter-temporal Cross-substitution
Lenski et al. (2013)	U.S.	2009	Scrappage, CARS	Vehicle fleet Fleet fuel efficiency Vehicle lifetime and VMT Lifecycle	Self-selection
Li et al. (2013)	U.S.	2009	Scrappage, CARS	Vehicle fleet Fleet fuel efficiency Vehicle lifetime and VMT	Inter-temporal Cross-substitution Self-selection Rebound

Study Designs

All studies use a quasi-experimental approach with combined cross-sectional data and time-series methods with aggregate data. See Table 4 for a description of the study design elements of the studies reviewed. Most studies use repeated cross-sectional vehicles sales data, but two of these only include hybrid vehicle sales (Diamond, 2009; Gallagher and Muehlegger, 2011). Units of analysis are varied in these studies and range from counties (Lenski et al., 2013) to states (Diamond, 2009; Zolnik, 2012) to countries (Li et al., 2013).

The outcome variables in these studies are most commonly reduction in total CO_2 and fiscal cost per ton of CO_2 emissions reduction. Regression models are typically used to calculate the change in the vehicle fleet (by make, model, and year) and/or the change in the fuel efficiency of the fleet (Zolnick, 2012). These models control for a range of variables, frequently including population attributes, vehicle attributes, fuel price, fleet eligibility, and VMT or air pollution levels. These models are used to understand vehicle fleet composition and fuel economy with and without the program by capturing the inter-temporal and cross-substitution effects. Then, estimates of lifetime VMT of the vehicle fleet with and without the program are based on assumptions or available data. The total CO_2 emissions reductions from these programs appear to be highly sensitive to these estimates. A number of approaches to estimating lifetime VMT are used: simple VMT averages based on travel surveys such as the National Household Travel Survey (NHTS), vehicle survival probabilities from the NHTS, and estimates based on the CARS surveys or odometer readings. The CARS participant survey showed that trade-ins were driven an average 9,412 miles in the prior year and that participants were planning on keeping the vehicles for another 2.5 years without the program. Odometer readings were also recorded from the scrapped vehicles; however, vehicle mileage was underestimated due to odometer rollover. Zolnick (2012) used 2009 NHTS average odometer readings by make and model to adjust the CARS odometer reading data in his study. Estimates of self-selection bias and rebound effects are also included in some studies. The magnitude of the rebound effects are documented in Table 4.

Notable aspects of specific studies are as follows:

The CARS transaction data set is used by Lenski et al. (2013) as inputs to GREET[3] model scenarios with and without the program. The use of the GREET study allows for

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[3] Description of GREET from Argonne National Laboratory: "To fully evaluate energy and emission impacts of advanced vehicle technologies and new transportation fuels, the fuel cycle from wells to wheels and the vehicle cycle through material recovery and vehicle disposal need to be considered. Sponsored by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE), Argonne has developed a full life-cycle model called GREET (Greenhouse gases, Regulated Emissions, and Energy use in Transportation). It allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle/vehicle-cycle basis. The first version of GREET was released in 1996. Since then, Argonne has continued to update and

the representation of the lifecycle impacts of the CARS program. In fact, this is the only study reviewed here that attempts to quantify this impact. The study also uses results from CARS participant survey data to account for scrapped vehicle survival rates and declining distanced traveled (related to self-selection, described above). The study used counties as the unit of analysis and found that the program largely benefited urban areas.

The evaluation of GHG effects of the CARS scrappage program by Li et al. (2013) differs from Lenski et al. (2013) in that it uses vehicle purchase data for multiple years (2007 to 2009) before, during, and after the implementation of the program for both the U.S. and Canada (countries are the unit of analysis in this study). The study uses the Canadian auto market as a control group in a difference-in-difference[4] repeated cross-section analysis. The use of total vehicle sales and the Canadian control group allows for statistical analysis of inter-temporal and cross-substitution effects of the programs. The analysis also uses age-specific survival and distance effects from Lu (2006) and includes a range of rebound effects from the literature to provide a lower and upper bound on the GHG emission reduction estimates. The study finds that inter-temporal and cross-vehicle substitution effects are significant: 45 percent of the program spending went to consumers who would have bought a new vehicle anyway.

Diamond (2009) examines the change in state level hybrid vehicle market share using a repeated cross-sectional regression model. Hybrid vehicle registration data by state from 2001 to 2006 were acquired from a private source and thus the data set includes multiple samples collected before, during, and after policy program implementation. The model estimates change in hybrid market share but does not include inter-temporal and cross-substitution. Overall, the study finds that hybrid vehicle adoption is strongly linked to fuel prices (elasticities range from 7.2 to 9.3) and less so to hybrid incentive programs (elasticities range from 0.8 to 1.5). HOV lane access for hybrid vehicles is not found to have a significant impact on hybrid market share. The study also presents evidence that upfront excise tax or sales tax waivers or rebates may be more effective than delayed income tax credits.

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expand the model. The most recent GREET versions are the GREET 1 2012 version for fuel-cycle analysis and GREET 2.7 version for vehicle-cycle analysis. GREET was developed as a multidimensional spreadsheet model in Microsoft Excel. This public domain model is available free of charge for anyone to use. For a given vehicle and fuel system, GREET separately calculates the following: Consumption of total energy (energy in non-renewable and renewable sources), fossil fuels (petroleum, natural gas, and coal together), petroleum, coal and natural gas; emissions of CO2-equivalent greenhouse gases - primarily carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O); and Emissions of six criteria pollutants: volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NOx), particulate matter with size smaller than 10 micron (PM10), particulate matter with size smaller than 2.5 micron (PM2.5), and sulfur oxides (SOx)." (http://greet.es.anl.gov/)

[4] An econometric technique that measures the effect of a program over a period of time.

Gallagher and Muehlegger's (2011) experimental design for hybrid market share is similar to Diamonds' 2009 study. The examination of hybrid market share is extended to examine reductions in GHG emissions. The study does include indirect effects. However, the study finds that a 1 percent increase in tax incentive is associated with 1.2 percent increase in hybrid sales. This study also finds that fuel prices have a more significant impact than do incentive programs, and incentives given at the point of sale (sales tax and rebates) are more effective than income tax credits.

Like the two studies just described, Chandra et al. (2010) estimate the effect of incentives on hybrid vehicle sales at the sub-national governmental level of provinces in Canada but expand the analysis to include all vehicle sales (not just hybrid vehicles) including make, model, and year from 1989 to 2006 (from DesRosiers Automotive Consultants, Inc.). An advantage of the Canadian case study is that no federal incentive programs existed at this time and the provincial policies only included rebates at the time of the sales transaction (and thus are not dependent on income). The design includes inter-temporal and cross-substitution effects. Vehicle survival is represented with an average survival rate for all vehicles, which would tend to introduce aggregation error into the analysis. This study finds that the state-level rebates are responsible for only about 26 percent of hybrid vehicle sales and that the programs prevented some purchases of fuel efficient cars that were not hybrid vehicles. The study estimates that the cost of saving one ton of GHG emissions from the program was $195 (Canadian dollars), while one ton of GHG emissions was only valued at $2 by the Chicago Climate Exchange in 2004. As a result, this study concludes that Canadian programs are not cost-effective.

Federal hybrid incentives for the U.S. are also examined by Beresteanu and Li (2011). It is the only study that employs an equilibrium model of the entire U.S. auto market, based on vehicle sales data and household level data by metropolitan statistical areas (MSA). The study uses average vehicle lifetime (15 years) and distance traveled (12,000 miles traveled per year) for both the "with" and "without" the program scenarios, and thus does not account for differential vehicle survival rates and distance-related biases. The model controls for the connection between vehicle price and vehicle sales, as well as fuel price, local policies that support hybrid vehicles (i.e., HOV lanes and free parking), and household characteristics including household size, renter/homeowner, number of children in household, time to work, and income. The study finds that modest tax credits (i.e., up to $2,000) before 2005 increased sales of hybrid vehicles by 5 percent and more generous credits in 2006 (i.e., up to $3400) increased hybrid vehicle sales by 20 percent; however, the small market share of hybrid vehicles renders GHG emissions savings inconsequential. This study also finds that an increase in fuel taxes or fuel price is more cost-efficient than incentive programs, and that rebates are more effective incentives than tax credits or deductions.

Table 4: Summary of Study Designs

Study	Data	Type and Time	Unit of Analysis	Model	Outcome Variable	Independent Variables	Controls
Beresteanu and Li (2011)	Vehicles sales and household data by MSA	Repeated cross-sectional all auto sales from 2000 to 2006 and 2001 NHTS	MSA (22)	Random coefficient utility model of consumer vehicle choice (household data) Equilibrium model auto market supply (vehicle sales data)	Auto market CO_2 Fiscal cost per ton of CO_2	Incentives Vehicle sales including inter-temporal and cross-substitution effects Average vehicle lifetime of 15 years and 12,000 annual miles Marginal mpg improvement of new vehicle relative to one without incentive	Household attributes Vehicle endogenous market price Fuel price Local incentives
Chandra et al. (2010)	Vehicle sales by CAN Province	Repeated cross-sectional from 1989 to 2006	Province	Regression	Hybrid sales Fiscal cost per ton of CO_2	Incentives Hybrid vehicle sales including inter-temporal and cross-substitution Average vehicle lifetime of 15 years and average annual VMT by province and year Marginal mpg improvement of new vehicle relative to one without incentive	Province specific attributes Vehicle model attributes Vehicle preferences over time Fuel price
Lenski et al. (2013)	CARS transaction	Cross-sectional 2 months in 2009	County	CARS transaction data inputs to GREET model scenarios	CO_2 Fiscal cost per ton of CO_2	Incentives Trade-in-vehicle and new vehicle category, year and mpg Trade-in odometer reading Expected lifetime 2.5 years from CARS survey [a] Expected annual VMT same as prior year 9,412 from CARS survey [a] 4.3% annual decrease in expected annual VMT Marginal mpg improvement (up to 0.7 mpg) of new vehicle relative to one without CARS Lifecycle effects accelerated vehicle manufacturing and disposal	GREET model
Li et al. (2013)	Vehicles sales	Repeated cross-sectional from 2007 to 2009	Country	Difference-in-Difference regression with Canada as U.S. control	CO_2 Fiscal cost per ton of CO_2	New vehicles by month, year, vehicle type for U.S. and Canada with month and eligibility to account for inter-temporal and cross-substitution effects Age-specific survival and distance by vehicle type based on 2001 NHTS (Lu, 2006) (8,531 average annual VMT and 7 years expected lifetime) Avoided lifetime VMT from trade-in-vehicle Rebound effects from 10% to 5% Marginal mpg improvement of new vehicle relative to one without CARS	Control group: Canada Fuel price Eligibility Vehicle attributes Supply/demand shocks

[a] Based on CARS participant survey which showed that trade-ins were driven an average 9,412 miles in the prior year and that participants were planning on keeping the vehicles for another 2.5 years without the program.

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