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Evaluating "Cash-for-Clunkers"

Program Effects on Auto Sales and the Environment

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RESOURCES FOR THE FUTURE

Evaluating “Cash-for-Clunkers”: Program Effects on Auto Sales and the Environment

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Abstract

“Cash-for-Clunkers” was a $3 billion program that attempted to stimulate the U.S. economy and improve the environment by encouraging consumers to retire older vehicles and purchase more fuel-efficient new vehicles. We investigate the effects of this program on new vehicle sales and the environment. Using Canada as the control group in a difference-in-differences framework, we find that the program increased new vehicle sales by about 0.36 million during July and August of 2009, implying that approximately 45 percent of the spending went to consumers who would have purchased a new vehicle anyway. Our results suggest no gain in sales beyond 2009 and hence no meaningful stimulus to the economy. In addition, the program will reduce CO_2 emissions by only 9 to 28.4 million tons, implying a cost per ton ranging from $91 to $288 even after accounting for reduced criteria pollutants.

Key Words: stimulus, Cash-for-Clunkers, auto demand, CO_2 emissions

JEL Classification Numbers: Q50, H23, L62

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1. Introduction

Amid a major recession and growing concerns about the environment, many countries have adopted programs that encourage consumers to trade in their old, inefficient vehicles, in exchange for more efficient ones. In the United States, the Cash-for-Clunkers program provided eligible consumers a $3,500 or $4,500 rebate when trading in an old vehicle and purchasing or leasing a new vehicle. Many other countries, such as France, the United Kingdom, and Germany, have similar programs, which generally share the same two goals: to provide stimulus to the economy by increasing auto sales, and to improve the environment. The U.S. program received enormous media attention and many considered the program to be a great success; during the program's nearly one-month run, it generated 678,359 eligible transactions and had a cost of $2.85 billion.[1] But as a matter of economic theory, it is typically quite difficult to achieve multiple goals with a single policy. The large fiscal cost and public enthusiasm for these programs, and their widespread use around the world, raise the question of just how effective are they at meeting their economic and environmental goals.

While several other studies have analyzed particular aspects of the program, this study estimates the composition of the fleet of vehicles that would have been sold in the absence of the program, permitting a comprehensive evaluation of the program effect on vehicle sales, the environment and economic activity. First, we examine the program's effects on new vehicle sales both during the program and in the several months before and after the program. Many

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[1] Transportation Secretary LaHood declared the program to be "wildly successful" at the end of the program, while two Op-Ed articles in the Wall Street Journal on August 2nd and 3rd raised doubts about whether the program truly increased sales and stimulated the economy. They argued that the program would most likely result in the shifting of future vehicle demand to the present and could hurt the sales of other goods.

observers of the program were concerned that it would primarily pull demand from adjacent months, and therefore it would provide little short-term stimulus and even less in the longer term. Consequently, we focus on two types of changes in consumer behavior caused by the program: switching from purchasing low fuel-efficiency to high fuel-efficiency vehicles, and shifting the purchase time to take advantage of the program's incentives.

Second, we evaluate the program's cost-effectiveness in reducing gasoline consumption and carbon dioxide (CO_2) emissions by comparing total gasoline consumption as well as emissions of CO_2 and criteria pollutants with and without the program. There exist many federal subsidy programs aiming to reduce U.S. gasoline consumption and CO_2 emissions such as tax credits for ethanol blending and income tax incentives for purchasing hybrid vehicles. Our cost-effectiveness analysis permits a comparison across the different programs.

The basis for these evaluations is the difference-in-differences (DID) analysis in a vehicle demand framework based on monthly sales of new vehicles by model from 2007 to 2009. The U.S. market constitutes the treatment group in the analysis. We use Canada as the control group based on two observations as well as some statistical evidence. First, Canada did not have a similar program, while nearly a dozen European countries did in 2008 and 2009. Second, the Canadian auto market is probably the most similar to the U.S. market: in both countries in recent years before the recession, about 13-14 percent of households annually purchased a new vehicle; characteristics of vehicles sold are similar; and pre-program time trends are similar. Although some differences in pre-program sales trends exist, they can be largely explained by differences in unobserved demand factors that we account for in our empirical model.

The DID analysis shows that the program increased sales of vehicles that were eligible for the rebate (eligible vehicles) and lowered sales of ineligible vehicles during the program period. Furthermore, within eligible vehicles, the positive effect was larger for those with higher fuel efficiency – which yield a higher rebate under the program. The negative effect on ineligible vehicles was stronger for those that barely missed the eligibility requirement, implying that the program caused consumers to substitute from these vehicles to eligible vehicles. We find that the program resulted in lower sales in the months before and especially after the program, and that the effect on sales weakened over time. The empirical results thus suggest that the program resulted in consumer demand shifting from ineligible vehicles to eligible ones as well as shifting from pre- and post-program periods to program periods, with the inter-temporal shift having the strongest impact.

With the parameter estimates from the DID analysis, we simulate vehicle sales in the counterfactual scenario of no program. We find that the program resulted in a sales increase of only 0.36 million during July and August of 2009, implying that of the 0.66 million vehicles purchased under the program, 0.30 million would have been purchased anyway during these two months. The program effect on vehicle sales eroded further when we look at a longer time horizon: the increase in vehicle sales during June to December of 2009 was practically zero. Therefore, we conclude that the program provided little economic stimulus. In addition, our simulation results show that Toyota, Honda and Nissan benefited from the program disproportionally more than other firms: with a combined market share of around 38 percent before the program, they accounted for more than 50 percent of the increased sales.

Based on the simulation results on vehicle sales, we estimate the differences in total gasoline consumption, CO_2 emissions, and four criteria pollutant emissions (carbon monoxide, volatile organic compounds, nitrogen oxides and exhaust particulates) with and without the program. We provide the results for 12 different cases, across which parameter and behavior assumptions vary. The total reduction in gasoline consumption ranges from 924.4 to 2930.8 million gallons while that in CO_2 emissions ranges from 9 to 28.4 million tons. After accounting for the program's benefit in reducing criteria pollutants, we estimate that the program's cost of CO_2 emissions reduction ranged from \$91 to \$288 per ton of CO_2 while that of gasoline consumption reduction ranged from \$0.88 to \$2.80 per gallon.

Several recent studies have evaluated particular aspects of the Cash-for-Clunkers program. Knittel (2009) estimates the implied cost of the program in reducing CO_2 emissions. Council of Economic Advisors (CEA 2009) and Cooper *et al*. (2010) analyze program impacts on vehicle sales and employment. National Highway and Traffic Safety Administration (NHTSA, 2009) also examines program effects on gasoline consumption and the environment. The major difference between our analysis and the aforementioned studies lies in the fact that we use the DID approach to estimate counterfactual sales by vehicle model in the absence of the program. Knittel (2009) does not establish the counterfactual and does not examine program effects on vehicle sales. The other three studies estimate the sales effect based on heuristic rules and aggregate sales data and do not examine consumer substitutions across models and over time.

A recent study by Mian and Sufi (2010) is more closely related to ours in that we both establish counterfactual outcomes by exploiting variations in program exposure across different areas. The key differences are that they use variations across U.S. cities in ex-ante exposure to the program, but they do not look at environmental outcomes. They show an almost identical short-term effect (July and August) to ours and they argue that by as early as March 2011, the program effect was completely reversed. Copeland and Kahn (2011) use a time-series approach to examine the program effect on sales and on production. They find a slightly larger short-term effect on vehicles sales but also conclude that by January 2010, the cumulative effect of the program on sales was essentially zero.

Carefully analyzing the counterfactual is important for estimating the environmental benefits of the program. For example, we find a smaller cost per ton of CO_2 reduction than Knittel (2009) because we account for the difference between total CO_2 emissions during the remaining lifetime of the trade-in vehicles and the emissions from the new vehicles purchased to replace them, and the fact that the whole fleet of new vehicles purchased in the presence of the program would be more fuel efficient than that without the program; whereas Knittel (2009) only considers the first effect. Not analyzing the counterfactual fleet without the program can thus underestimate the program's environmental benefit.

The rest of the paper is organized as follows. Section 2 describes the program and the data in detail. Section 3 lays out the empirical framework. Section 4 provides estimation results and analyzes the program effect on auto sales. Section 5 examines the program impact on gasoline consumption and CO_2 emissions, and Section 6 concludes.

2. Background and Data

In this section, we first discuss program background, including the timeline and eligibility rules. Next, we present the data set that are used in the empirical analysis.

2.1 Program Description

As Figure 1 shows, the Consumer Assistance to Recycle and Save Act (CARS) was passed by the House of Representatives on June 9th, 2009 and by the Senate on June 18th, and was signed into law by the President on June 24th. This law established the Cash-for-Clunkers program, a temporary program granting subsidies to car owners who trade in their older, fuel inefficient vehicles to purchase a new and more efficient vehicle. The traded-in vehicle would then be dismantled in order to ensure that it does not return to the road. The program was officially launched on July 27th, 2009 and terminated ahead of schedule on August 25th, 2009. It generated 678,359 eligible transactions at a cost of $2.85 billion.[2] Originally, the program was planned as a $1 billion program with an end date of November 1st, 2009.

The Cash-for-Clunkers program was intended to help reduce the number of old and less fuel efficient vehicles (i.e. clunkers) on the roads as well as shift demand towards more fuel

[2] Statistics are from press releases at http://www.cars.gov/official-information.

efficient new vehicles. The program outlined four requirements that the trade-in would have to meet in order to be eligible, as shown in Table 1A. The requirements vary according to the size and class of the vehicle. The first three requirements ensured that the traded-in vehicle would otherwise be on the road had it not been for the program: the trade-in vehicle must be drivable; it must have been continually insured and registered by the same owner for the past year; and it must not be older than 25 years for all vehicles except for category 3 vehicles. The fourth rule ensured that the vehicle is in fact a "clunker": it must have a combined fuel efficiency of 18 mpg or less for all vehicles except category 3 trucks.[3]

Table 1B shows the minimum MPG a new vehicle needed to qualify. The MPG requirement was 22 for passenger automobiles, 18 for category 1 trucks, and 15 for category 2 trucks. Category 3 trucks, on the other hand, had no minimum fuel efficiency requirement, but they could only be traded in for category 3 trucks. Finally, the MSRP of the new vehicle could not exceed $45,000. Table 1B shows that the stringency of the MPG requirement is greatest for passenger cars and decreases across the truck categories. For example, a new passenger car must have an MPG improvement of at least 4 over the trade-in vehicle in order to qualify for the $3,500 rebate while a 10 MPG improvement is needed for the $4,500 rebate. For a new vehicle in category 1, the requirements on the MPG improvement is 2 and 5 for the two rebate levels. The requirements become still less stringent for category 2 and 3 vehicles.

2.2 Data Description

We collect data on monthly vehicle sales for all models in the United States and Canada from 2007 to 2009 from Automotive News. We combine these data with vehicle MPG data from the Environmental Protection Agency's fuel economy database as well as vehicle prices and other characteristics from Wards' Automotive Yearbook. Our data include 16,814 observations of monthly vehicle sales. We define a model as a country-vintage-nameplate (e.g., a 2007 Toyota Camry in the United States) and we have 1,436 models in the data. Almost all the models sold in Canada are available in the United States.

Table 2 provides summary statistics of the data set. Based on the eligibility rules, 1,008 of the 1,436 vehicle models meet the requirement and could be eligible for the rebate during the program (henceforth, eligible vehicles). Among the 16,776 observations, about 70 percent of

[3] Category 1 trucks are "non-passenger automobiles" including SUVs, medium-duty passenger vehicles, pickup trucks, minivans and cargo vans. Category 2 trucks are large vans or large pickup trucks whose wheelbase exceeds 115 inches for pickups and 124 for vans.

sales in both countries are for eligible vehicles. As shown in the table, the eligible vehicles have much higher sales than ineligible ones. Although the average sales per model in the United States are much higher than in Canada, the number of new vehicles sold per households is 13-14 percent in both countries. On average, the eligible vehicles are cheaper and, by definition, more fuel-efficient than ineligible ones. The average prices are very similar in the two countries across both categories. Because a higher proportion of light truck models is available in Canada, the average fuel efficiency of models sold in Canada in both categories is lower than in the United States. The sales-weighted MPG of new vehicles is lower in Canada, likely due to higher gasoline prices and lower average household income.

To examine the effectiveness of the program on energy consumption and the environment, we use the public database for the Cash-for-Clunkers program from www.cars.gov. The data set provides (dealer-reported) information on the trade-in and new vehicles for each transaction during the program. There are 678,539 transactions in the data set. We remove transactions that are subject to reporting error (e.g., reported MPG that does not meet the eligibility criteria). In addition, we delete 2,278 category 3 vehicles and 6,169 leased vehicles in order to be consistent with our demand analysis on new vehicles. After removing 18,959 records, there are 659,400 observations of trade-in and new vehicles under the program.

Table 3 shows the summary statistics on trade-in and new vehicles. This table demonstrates that consumers were trading in more light trucks than cars, and that these trucks were newer than the cars. The average rebate amount is $4,214 and the total payment on these vehicles is $2.78 billion (out of $2.85 billion on all transactions).

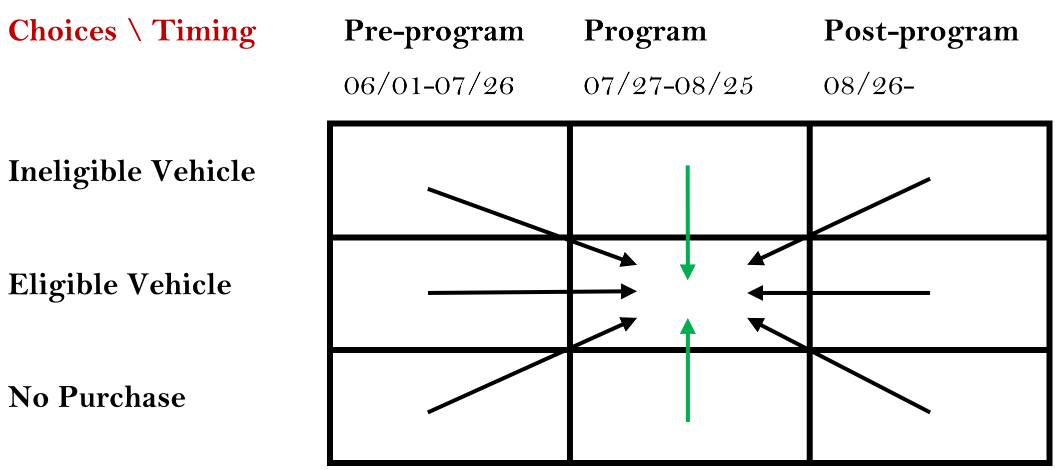
3. Empirical Strategy

In this section, we first discuss the channels through which the program could affect vehicle sales. We then describe our empirical model.

3.1 Potential Program Effects

In our analysis, we assume that the program did not affect vehicles sales prior to June 2009. Although some consumers may have known about the bill before the House passed it on June 9th, we expect that the uncertainty surrounding the eligibility requirements as well as the bill's final passage would greatly limit its effect before June 9th. In fact, our estimation results show that there is no significant effect on sales even in June. The program period is defined from July 27th to August 25th. Although the program retrospectively recognized qualified sales from July 1st until the official start date, the total number of these sales was only 30,317, which is less than the average daily sales during the first week of the program.

Because an automobile is a durable good, the program could affect vehicle sales before, during, or after the program period. During the program period, some consumers who would have purchased an ineligible model or chosen not to purchase a new vehicle may choose to purchase an eligible model instead. In addition, the program could result in consumers changing the purchase time in order to coincide with the program period (i.e., intertemporal substitution). In the absence of the program, these consumers could have purchased an eligible or an ineligible vehicle in other periods. Both channels would increase total vehicle sales and improve fleet fuel-efficiency. To a large extent, the design of the program in achieving the stimulus purpose was to pull demand forward from a *sufficiently* distant future when the economy was expected to be stronger. Thus, the time horizon over which the intertemporal substitution occurs is crucially important to the stimulus purpose but not so for the environmental purpose. The graph below illustrates different substitution channels.



The degree of these substitutions could vary over product space as well as over time for several reasons. First, there could be a stronger substitution to eligible vehicles from vehicles that barely miss the MPG requirement, compared to the substitution from vehicles that have much lower fuel efficiency. This is due to the fact that higher fuel-efficiency vehicles tend to compromise on certain amenities such as horsepower and engine size, and thus a consumer would face a smaller trade off in amenities by only marginally increasing fuel efficiency. In addition, because high MPG vehicles could be eligible for a higher rebate ($4,500 versus $3,500) the program could have a stronger effect on the vehicles eligible for the higher rebate. Second, the substitution could exhibit heterogeneity over time. Intuitively, the intertemporal substitution should be stronger right before or after the program than farther away from the program. Moreover, because the length of the program is not fixed and runs out when the designated amount of stimulus money is used up, the program could have a stronger stimulus effect at the beginning of the program period. In fact, the initial one billion dollars were used up within a week while the additional two billion dollars lasted for three weeks.

3.2 Empirical Model

We implement the difference-in-differences (DID) method in a regression framework where the Canadian auto market is used as the control group for the U.S. market. Our DID regression estimates how the program affected vehicle sales before, during, and after the program period on a monthly basis given the vehicle's eligibility and other characteristics. The causal interpretation hinges on the identifying assumption that (unobserved) demand and supply shocks at the time of the program are the same in the two countries. The initial analysis on the Canadian auto market presented in Section 4.1 suggests that Canada is a valid control group to estimate underlying trends that are not affected by the program but that do affect vehicle sales (such as economic shocks that occur at the same time as the program).

The regression model is based on monthly sales of new vehicles by vehicle model. Let *c* index country (United States or Canada), *t* index year, *m* index month, and *j* index vehicle nameplate (e.g., Ford Focus). We define a vehicle model as a country-year-nameplate (e.g., a 2009 Ford Focus in the United States) and use *ctj* as the index. By including interactions of month dummies with eligibility in a regression framework, we are able to specifically capture the effect across the months, allowing us to identify the extent of intertemporal substitution. The following equation allows us to disentangle monthly program effect on sales for eligible and ineligible vehicles.

$$
\begin{aligned}
log(q_{ctmj}) = {} & E_{ctj} P_{ctm} \alpha^E_{tm} + E_{ctj} P_{ctm} |\Delta GPM_{ctj}| \beta^E_{tm} \\
& + I_{ctj} P_{ctm} \alpha^I_{tm} + I_{ctj} P_{ctm} |\Delta GPM_{ctj}| \beta^I_{tm} \\
& + x_{ctmj}\, \alpha + \xi_{ctj} + E_{ctj} \eta^E_{cm} + I_{ctj} \eta^I_{cm} + E_{ctj} \delta^E_{tm} + I_{ctj} \delta^I_{tm} + \varepsilon_{ctmj}, \quad \textbf{(1)}
\end{aligned}
$$

where q_{ctmj} is the sales of vehicle model j.[4] E_{ctj} is the eligibility dummy, equal to one for any vehicle in either country that meets the program requirement (irrespective of whether the program is in effect) and zero otherwise. I_{ctj} is a dummy for ineligible vehicles and is equal to one for any vehicle in either country that does not meet the program requirement. P_{ctm} is a dummy variable equal to one for months when the program may have had an effect (e.g., June to December of 2009) in the United States and zero otherwise. GPM is gallons per mile and $\Delta GPM_j = 1/MPG_j - 1/MPG^*$ where MPG^* is the MPG requirement for rebate eligibility, which varies across vehicle categories as discussed in Section 2.1. Thus, $|\Delta GPM_{ctj}|$ measures how far the vehicle's fuel efficiency is from the requirement. The first two terms on the right side capture the program effect on eligible vehicles with the second term allowing the program effect to depend on vehicle fuel efficiency. Since there are two rebate levels ($3,500 and $4,500) and the size of the rebate depends on the difference between the MPG of the new vehicle and that of the trade-in vehicle, consumers may substitute towards eligible vehicles with higher MPGs as these vehicles are more likely to provide them with a $4,500 rebate.

The next two terms capture the effect on ineligible vehicles. We expect the program effect on ineligible vehicles to be correlated with fuel efficiency as well: consumers are more likely to switch from barely ineligible vehicles to eligible vehicles, rather than substitute away from vehicles much farther outside the eligibility cut-off. Due to the trade-offs between vehicle size/horsepower and fuel efficiency, consumers likely suffer a smaller sacrifice in vehicle size or horsepower by switching from barely ineligible vehicle to eligible ones, rather than from vehicles that are far below the MPG requirements.

Note that the first four terms are zero for the observations in Canada. These four terms capture the program effect on vehicle sales in the United States, and allow for different effects across vehicles. However, interpreting these coefficients as causal effects of the program hinges on the assumption that Canada is a valid control group. The other variables in the equation help in identifying the impact of the program on sales by controlling for country and vehicle observed and unobserved attributes.

[4] For all the regressions presented in the paper, we also estimate a multinomial logit model in the linear form (Berry 1994) where we assume that consumers have a total of *J* vehicle models plus an outside good indexed by *0* (i.e., not purchasing a new vehicle) to choose from in a given month. The dependent variable is $\log(S_{ctmj}) - \log(S_{ctm0})$ with S_{ctmj} and S_{ctm0} being the market shares of model *j* and the outside good that captures the decision of not purchasing a new vehicle respectively. The market size is the number of households in the two countries. The results are very close to the results from the linear models shown in Section 4.

x_{ctmj} is dollars per mile (gasoline price/MPG). ξ_{ctj} denotes model (i.e., country-year-nameplate) fixed effects, which control for month-invariant observable and unobservable vehicle attributes (such as horsepower, weight, and product quality), as well as month-invariant demand shocks at the model level. η_{cm}^{E} and η_{cm}^{I} are country-month fixed effects to capture country-specific seasonality for eligible and ineligible vehicles (such as December holiday effect). ξ_{ctj}, η_{cm}^{E} and η_{cm}^{I} are all country-specific fixed effects, controlling for country-specific demand and supply shocks that affect the level of vehicle sales (these would be equivalent to household or firm dummies in a canonical DID example). δ_{tm}^{E} and δ_{tm}^{I} are common year-month fixed effects for eligible and ineligible vehicles (these would be equivalent to time dummies in a canonical DID example). Because these fixed effects are used to capture demand shocks for the two groups of vehicles that are common in the two automobile markets, they give rise to the control group interpretation for the Canadian market.[5] Finally, ε_{ctmj} is the random demand shock.

3.3 Testing for Pre-existing Trends

Our empirical models control for unobservables in several dimensions by including model fixed effects ξ_{ctj}, common year-month fixed effects δ_{tm}, and country-specific seasonality η_{cm}. Nevertheless, as we discussed above, the unbiasedness of the coefficient estimates hinges on the identifying assumption that the time trends in demand and supply are the same in the two countries. Otherwise, we risk interpreting preexisting differences in time trends as the effect of the program.

This identifying assumption cannot be directly tested, but we can take advantage of the data before the program period to test for differences in pre-existing trends. Similarity before the program would support the assumption that the trends are the same during and afterwards. This strategy has been used in many previous studies that have data for multiple periods before the treatment (e.g., Eissa and Liebman 1996, and Galiani et al. 2005).

The test can be carried out by estimating a modified version of equation (1) using the data before June 2009, excluding the first four terms, and adding country-month dummies interacted with the eligibility dummy:

$$log(q_{ctmj}) = E_{ctj} D_{ctm} \tau_m^{E} + I_{ctj} D_{ctm} \tau_m^{I}$$

$$+x_{ctmj}\, \alpha + \xi_{ctj} + E_{ctj}\eta_{cm}^{E} + I_{ctj}\eta_{cm}^{I} + E_{ctj}\delta_{tm}^{E} + I_{ctj}\delta_{tm}^{I} + \varepsilon_{ctmj}\,, \quad \textbf{(2)}$$

[5] Because not all models are available in both countries, we cannot use year-month-model fixed effects.

where D_{ctm} is a month dummy and is equal to one for February-May 2009 in the United States. The January dummy and the corresponding dummy variables for Canada are absorbed by model fixed effects ξ_{ctj}. Large estimates of τ_m^E and τ_m^I could imply that vehicle sales in the United States were affected by underlying factors present in the months prior to the program period that were not present in Canada. That is, large estimates of τ_m^E and τ_m^I would invalidate Canada as a control group.

The economic downtown that started in the second half of 2008 raises a particular concern that the demand and supply trends were not similar in the two markets before or during the program. The recession in the United States was driven by the housing market crisis; the mortgage default rate increased dramatically and housing prices fell sharply at the onset of the crisis. By comparison, housing prices in Canada continued to increase until late 2008. In addition, the credit market in Canada was not impaired and did not experience the "credit crunch" as in the United States. As a result, the downturn in Canada was milder and the auto market in Canada did not contract as much as in the United States.[6] To address concerns about the downturn, we drop the data from June to December of 2008 as an alternative estimation to the estimation using the full data set. If the downturn were causing significant bias, we would expect to obtain different results by omitting these observations. As we show below, we obtain qualitatively similar results from these two estimations.

4. Estimation Results

We discuss the validity of using Canada as the control group. We then show the estimation results for the diff-in-diff regressions.

4.1 Canada as the Control Group

We provide qualitative and quantitative support for using Canada as the control group. First, Canada did not have a similar program, whereas many European countries including Germany, France, Italy and Spain did in 2008 and 2009. Although Canada has a Retire Your Ride Program that started in January 2009, the program is not comparable to the Cash-for-Clunkers program for at least three reasons. First, the program provides only CA$300 worth of credit for eligible participants (owners of pre-1996 model-year vehicles that are in running

[6] Although GDP growth, employment, and household spending slowed in Canada, the decrease in total new vehicle sales in the second half of 2008 was less severe in Canada: sales dropped 1.1% in Canada in 2008 (against a 1.5% increase in 2007) while they dropped 18% in the United States (against a 3% drop in 2007).

condition), compared to $3,500 or $4,500 offered in the United States. Second, the goal of the Canadian program is to improve air quality by encouraging people to use environmentally-friendly transportation, so the program is not tied to new vehicle purchases. Depending on the province, the credit can be a public transit pass, a membership to a car-sharing program, cash, or a rebate on the purchase of a 2004 or newer vehicle. Third, the program only retired about 60,000 vehicles during the first 15 months. Therefore, its effect on new vehicle sales (about 1.6 million annually) should be negligible.

The second justification for using the Canadian auto market as the control group is that it is probably the most similar to the U.S. market. About 13-14 percent of households purchased a new vehicle in recent years before the economic downturn in both countries. Table 2 (above) also shows that the vehicles sold have similar characteristics, although the U.S. market has a larger set of models. Figure 2 depicts monthly sales in logarithm of all, eligible, and ineligible new vehicles in the two countries from 2007 to 2009. By and large, the two series track each other well. A noticeable difference is that sales in Canada seem to have stronger seasonality (e.g., a larger hump during March-May each year), suggesting the importance of controlling for country-specific seasonality in our analysis.

Figure 2 shows that monthly sales of new vehicles in the two countries exhibit similar trends before the program. We now provide statistical evidence on the common trend assumption by using equation (2) to examine if the trends are the same in the two countries from February to May 2009, for each of the two groups of vehicles. Except for the first four program variables in equation (1), equation (2) includes the same control variables. The first estimation is based on the full sample while the second estimation is based on the sample without observations in the second half of 2008 to address the concern that the economic downtown affected the two countries differently.

The results are shown in Table 4. The first four parameters represent the difference in log sales between the United States and Canada for eligible vehicles for each of the four months prior to the program; the next four are for ineligible vehicles. If the pre-trends are the same in the two countries, these eight parameters should be small and should not be statistically different from zero. The regression results show that none of the parameters is individually significantly different from zero at any conventional significance level in either estimation. In addition, based on F-tests, we cannot reject that the trends are the same during the four-month period separately for eligible and ineligible vehicles. Note that the R-squared is higher for the shorter pre-program sample, which is consistent with the notion that the second half of 2008 was an atypical period.

Furthermore, the coefficients are not economically significant when compared to the program effects given by the parameter estimates discussed in the next section. For example, the coefficient on February for eligible vehicles in the first estimation is 0.02, suggesting that the increase in eligible vehicles in February (over January) is about 2 percent more in the United States than in Canada (or about 11,000 units out of 550,000 total sales in the United States). The coefficient on ineligible vehicles in May is 0.16, which appears to be large, but because ineligible vehicles account for less than 20 percent of total sales, this corresponds to only 16,000 units. Thus, we conclude that the two countries have similar trends prior to the program, which supports the use of Canada as a control group.

4.2 Difference-in-Differences Results

Table 5 reports parameter estimates and standard errors for the two estimations, one based on the full sample and the other based on the sample without the second half of 2008. This section discusses qualitative results and the next section presents the effects on sales implied by the parameter estimates. We only report the coefficient estimates associated with program effects (June to December of 2009) for the two groups of vehicles, noting that the full set of control variables described in equation (1) is included in the regressions. The interaction of the vehicle eligible dummy and $|\Delta GPM|$ allows for heterogeneous effects across vehicles.[7]

Overall, the parameter estimates have the expected signs. The directions of the program effects suggested by the parameter estimates are similar across the two estimations, and we focus on the full-sample results. The first two coefficient estimates suggest that the program reduced sales of eligible vehicles in June, although with no statistical significance. The coefficient estimates for July captures the combined effects from the pre-program period (July 1st-26th) and the program period (27th-31st). We would expect a decrease in sales during the pre-program period and an increase during the program period. Therefore, the combined effect could be positive or negative. The coefficient estimates using the full sample suggests that the program reduced the sales of eligible vehicles with low MPG while it increased the sales of those with high MPG. Similarly, the coefficients for August capture the combined effect during the program (August 1st-25th) and post-program (August 26th-31th). The coefficient estimates imply that the combined effect on eligible vehicles was positive and that the increase in sales was larger for eligible vehicles with high MPG. These results imply that the positive program effect outweighed the negative intertemporal substitution effect in both July and August.

[7] The mean of $|\Delta GPM|$ for eligible vehicles in 2009 in the United States is 0.67 with a range from 0 to 2.61. The mean of $|\Delta GPM|$ for ineligible vehicles is 0.67 with a range from 0.21 to 1.70.

The coefficient estimates for September suggest that the program reduced sales of eligible vehicles and that the decrease in sales was larger for eligible vehicles with high MPGs, consistent with consumers moving purchases forward to take advantage of the program. The parameter estimates for October and November suggest a negative effect on sales but the estimates are not statistically significant.

For ineligible vehicles, the parameter estimates suggest a negative effect from July to December and a larger effect for vehicles that miss the MPG requirement by a smaller margin (e.g., a smaller $|\Delta GPM|$). This is consistent with the fact that when consumers switch from these vehicles to eligible vehicles, they do not need to make a large sacrifice in other vehicle attributes such as horsepower and size, as discussed in Section 3.

4.3 Program Effect on New Vehicle Sales and Fuel Efficiency

Based on the parameter estimates from Table 5, we simulate new vehicle sales under the counterfactual scenario without the Cash-for-Clunkers program. The three plots in Figure 3 show sales effects for all, eligible, and ineligible vehicles from June to December of 2009 for the full sample. Dashed curves represent the 90 percent confidence intervals estimated by bootstrap. The point estimates show the differences between observed and simulated sales. The three corresponding plots in Figure 4 are based on parameter estimates using the short pre-program sample.

The results in both figures demonstrate the two channels through which the program affects vehicles sales (Section 3.1). First, the sales of eligible vehicles increased in July and August but decreased in adjacent months, implying that some consumers shifted their purchase timing. Second, the program had a strong positive effect for eligible vehicles in August but a negative effect for ineligible vehicles from July to December, especially in August, suggesting that some consumers switched from ineligible vehicles to eligible vehicles.

The effect on sales in June was negative but not statistically different from zero in both estimations, supporting our modeling assumption that the program effect before June was negligible. Because the program was implemented from July 27^{th}-August 25^{th}, the effect on total sales in July and August captures the (positive) effect during the program period and the (negative) effect due to intertemporal substitution just before or after the program. The net effects are both positive in July and August, although the effect in July is not statistically significant in the second estimation. The sales effects are all negative in September to November from both figures, particularly in the second estimation.

Figures 3 and 4 show the program effects by month, and Figure 5 shows the cumulative effects over different time horizons. The left-most point shows the cumulative effect during July-August. The points to the right show that the positive effects eroded over time. The top plot (based on the full sample) shows that the net effect is not statistically different from zero by the end of October. The bottom plot (based on the short pre-program sample) shows the same result by the end of September. Both plots show that the program likely had a short-lived effect on total vehicle sales.

Panel 1 of Table 6 reports monthly observed and simulated sales of new vehicles from June to December of 2009. Column (1) gives the observed sales while column (2) provides simulation results based on the parameter estimates from the full sample. Columns (3) and (4) show program effects on sales and the standard errors from bootstrap. Columns (5) to (7) provide results based on the parameter estimates from the short pre-program sample.

The cumulative effect on sales during July and August is estimated to be about 365,000 units and 357,000 units from the two estimations, respectively. This suggests that out of the 660,000 program participants, about 300,000 would have purchased a new vehicle during July and August even without the program. This underscores that one cannot take the number of vehicles sold through the program as the net program effect on vehicle sales. In addition, the estimate suggests that about 45 percent of the total spending ($1.4 billion) went to consumers who would have purchased a new vehicle anyway. Looking at a longer horizon, neither of the estimates suggests a net gain in sales during the period from June to December. Our estimate of the short-term effect on sales of about 360,000 is essentially identical to that of Main and Sufi (2010), despite the fact that different control groups are used. The point estimate is smaller than the 450,000 units from Copeland and Kahn (2011), but their estimate is within the 90 percent confidence interval of ours. In addition, all three studies broadly conclude that the program effect on sales is short-lived, with ours suggesting an even shorter effect.[8]

The second and third panels in Table 6 show the program effect on the average MPG and GPM (gallons per 100 miles) of the new vehicles for two time horizons: July-August, and June-December. During July and August, the program increased the average MPG of new vehicles by 0.65 (from 22.72 to 22.37) based on the full sample estimation. Over a longer time horizon, the effect on average MPG diminished: although the program increased sales of high MPG vehicles

[8] Copeland and Kahn (2011) argue that Canada had a milder downtown than the United States and as a result the rebound in the second half of 2009 could be milder as well. If our model was not able to address this, we should have under-estimated the negative effect on vehicle sales from September to December of 2009.

in July and August, it actually reduced sales of those vehicles in other months. Although our results suggest that the net effect of the program on vehicle sales was likely zero by the end of 2009, the program did increase the average MPG of new vehicles purchased.

Table 7 reports the sales effects for individual firms during July-August, and June-December of 2009. Toyota saw the biggest increase in sales while Chrysler saw the smallest in both time horizons based on the results from the full sample. Although only accounting for less than 40 percent of the market share, the three Japanese firms accounted for over 50 percent of the sales increase because they offer more fuel-efficient models than the U.S.-based firms. However, the results for the period of June-December provide evidence that the program did not lead to significant shifts in market shares among automakers.

5. Program Effects on Gasoline Consumption and the Environment

This section evaluates the effectiveness of the program in reducing motor gasoline consumption and CO_2 emissions. To that end, we compare the observed outcomes (i.e., gasoline consumption and CO_2 emissions) with the counterfactual outcomes in the absence of the program. In this section, we first discuss our method and then present the results.

5.1 Method

The program affects gasoline consumption and pollution through two channels. First, the program changes the fleet of new vehicles by causing some consumers to switch from fuel-inefficient vehicles to fuel-efficient vehicles, and by causing other consumers to purchase a new vehicle when they would not have otherwise. Second, it affects the fleet of used vehicles because the trade-in vehicles have to be scrapped. A complete analysis of the two channels would involve an equilibrium model of the auto market (including both new and used vehicles) that includes the dynamic effects of the program on both channels in a unifying framework.

Instead, we investigate the two channels based on the results from the previous section together with some simplifying assumptions. The first assumption is that the scrappage of the trade-in vehicles did not affect the remaining fleet of used vehicles. To the extent that the program reduced the availability of used vehicles in the second-hand market and hence increase used vehicle prices and prolong their service, our analysis would over-estimate the energy and environmental benefits of the program. The second assumption concerns the long-term program effect on vehicle sales. Our results from estimation on both samples cannot reject a zero net effect during June to December of 2009. In our analysis, we assume that total sales of new vehicles under the counterfactual would be the same as the observed total sales. Nevertheless, Table 6 shows that the fleet composition (i.e., average MPG) is different under the two scenarios.

We compare actual and counterfactual gasoline consumption. Actual consumption is given by:

$$GAS = \sum_j (q_j * VMT_j * GPM_j), \tag{3}$$

where q_j is the total sales of vehicles of model j during the period, and VMT_j is the lifetime vehicle miles traveled for model j. Lu (2006) estimates that the average lifetime VMT for passenger cars is 152,137 and that for light trucks is 179,954 based on the 2001 National Household Travel Survey. GPM_j is fuel consumption, which is measured in gallons per mile.

Under the above two assumptions, there are two components of counterfactual gasoline consumption: (1) the amount consumed over their remaining lifetime by the clunkers that were not traded in; and (2) the amount consumed by the new vehicles that would have been purchased from June to December of 2009 (with the time horizon to be discussed further below):

$$\widetilde{GAS} = \sum_{k=1}^{K} RVMT_k * GPM_k + \sum_j \tilde{q}_j * VMT_j * GPM_j\,, \tag{4}$$

where $RVMT_k$ is the remaining VMT of the trade-in vehicle k. We estimate the remaining VMT of each of the trade-in vehicles based on Lu (2006)'s estimates of age-specific survival probabilities and estimated annual VMT for passenger cars and light trucks as shown in Table 8. With this information, we predict age-specific remaining VMT for each type of vehicle, which is also shown in Table 8. Based on this method, the average remaining VMT of trade-in vehicles is 59,716 with an average remaining lifetime of 7 years.[9]

The second term in equation (4) is the total lifetime gasoline consumption of new vehicles sold from June to December in the absence of the program. $\tilde{q}_j$ is the simulated sales of model j based on estimation results in the previous section. We adjust $\tilde{q}_j$ proportionally so that total sales of new vehicles would be the same under the two scenarios.

We conduct our analysis under two cases regarding VMT_j in the second term of equation (4). In the first case, we use lifetime VMT for cars and light trucks. This assumes that without the Cash-for-Clunkers program, people would drive more (by the amount of VMT during the

[9] We compared the trade-in vehicles to the vehicles from the 2001 National Household Survey (NHTS), which is a national survey on vehicle holdings and travel behavior. On average, the trade-in vehicles have higher mileage than the vehicles with the same age from the 2001 NHTS. The difference is larger for relatively new vehicles. Therefore, our analysis could overestimate the remaining lifetime of the trade-in vehicles and the environmental benefit of the program. Nevertheless, the majority of the trade-in vehicles are 10-20 years old and the average MPG of these vehicles are quite close in these two data sets.

remaining lifetime of the clunkers). In the second case, we adjust VMT_j for these new vehicles so that total VMT from them and the clunkers under the counterfactual would be the same as the total VMT from new vehicles sold June-December of 2009 under the program. To the extent that having more vehicles (e.g., a new vehicle and a clunker) may induce extra travel under the counterfactual, the results from these two cases may bound the true effect on gasoline consumption.

5.2 Results

Table 9 presents the results for the cost-effectiveness analysis. Panels 1 and 2 are based on the estimation results from the full sample while panels 3 and 4 are based on the short pre-program sample. Panels 1 and 3 compare the lifetime gasoline consumption of new vehicles sold June-December of 2009 with the lifetime gasoline consumption of the less fuel efficient new vehicles that would have been sold June-December without the program, plus gasoline consumption from the trade-in vehicles during their remaining lifetime. Panels 2 and 4 adjust the VMT of new vehicles under the counterfactual scenario so that the total VMT under the two scenarios are the same.

Case 1 assumes that passenger cars have an average lifetime VMT of 152,137 and light trucks of 179,954. The result shows that the reduction in total gasoline consumption is about 2,930 million gallons, which is about 8 days of current U.S. gasoline consumption. Cases 2 and 3 allow more fuel efficient vehicles to have a higher VMT due to the lower fuel cost per mile of travel, i.e., the rebound effect. Earlier studies often find a long-run rebound effect around 0.20-0.30 while a recent study by Small and van Dender (2007) shows that the rebound effect could be declining largely due to income growth: their estimate of the rebound effect from 1966 to 2001 is 0.22 and that from 1997-2001 is 0.11. We incorporate the rebound effect of 0.1 and 0.5 in the second and third cases.[10] Because the vehicle fleet under the program is more fuel efficient than in the absence of the program, a positive rebound effect would mean a higher total VMT under the program. This would weaken the program effectiveness in reducing gasoline consumption. Therefore, the larger the rebound effect, the smaller the reduction in total gasoline consumption.

[10] The average MPG of passenger cars was 21.89 and that of light trucks was 17.45 in 2000. We use these values as the average MPGs corresponding to the lifetime VMT of 152,137 for passenger cars and 179,954 for light trucks (2001 NHTS).

Columns (3) to (6) present the dollar cost, from the perspective of government revenue, of a per unit reduction in gasoline consumption and CO_2 emissions. In calculating the unit cost, columns (3) and (4) take into account the benefit of the program in reducing four criteria pollutants (carbon monoxide, volatile organic compounds, nitrogen oxides, and exhaust particulates, i.e., CO, VOCs, NO_x, and exhaust $PM_{2.5}$). The emissions of these pollutants per mile of travel for trade-in vehicles are from MOBILE6, a computer program maintained by EPA that calculates emission factors for different types of vehicles. The model takes into account the fact that as a vehicle ages, the emissions level per unit of travel can increase dramatically, especially for older vehicles. Thus, as the counterfactual scenario would lead to higher overall emissions of these criteria pollutants due to the clunkers not being scrapped, we estimate through MOBILE6 how many tons of these four pollutants are reduced due to the program. To translate these reductions into monetary terms, we assume that the average damage per ton of the four pollutants is $74.5, $180, $250, and $1,170, respectively. The average cost for carbon monoxide is the average of the range reported by McCubbin and Delucchi (1994). The other three cost parameters are the median marginal damage from Muller and Mendelsohn (2009).

Columns (3) and (4) report the dollar costs of reducing one gallon of gasoline consumed and one ton of CO_2 through the program, with the co-benefit of reduced criteria pollutants. These costs range from $0.88 to $2.80 for each gallon of gasoline while the cost of reducing one ton of CO_2 ranges from $91 to $288. Without taking into account the co-benefit of reducing criteria pollutants, the unit costs increase as shown in columns (5) and (6): the range for the cost per gallon of reducing gasoline consumption becomes $1.02 to $3.25 while that for CO_2 reductions becomes $106 to $334.

The implied fiscal cost of CO_2 reduction from the program is much larger than the social cost of CO_2 (social marginal damages) recently estimated by the United States Government Interagency Working Group (2010). Based on three integrated assessment models, the workgroup provides a range of $5 to $65 per ton for 2010 emissions (in 2007 dollars) with a central value of $21. In addition, the implied cost of CO_2 reduction from our analysis is also far greater than projected marginal costs under several recent legislative proposals. For example, the allowance price for CO_2 under the Waxman-Markey cap-and-trade bill is projected to be $17-$22 per metric ton in 2020 in EPA's analysis in 2020 and $28 in CBO's analysis. This suggests that there are less costly alternatives in reducing CO_2 to achieve the level of reduction in the bill (i.e., 17 percent reduction from 2005 level by 2020). However, since the Cash-for-Clunkers program also provides the benefit of stimulating the economy and the estimated cost is a cost to the government rather than the marginal abatement cost, it is perhaps not fair to compare the implied carbon cost of the program to the allowance price in a national cap-and-trade program.

To put our results in perspective, we compare the cost-effectiveness of the program with two other federal programs that use tax expenditure to reduce gasoline consumption and CO_2 emissions. The first is an excise tax credit of 51 cents per gallon of ethanol blended with gasoline (generally at a 10 percent rate). Metcalf (2008) estimates that the cost of reducing gasoline consumption is about $2 per gallon and that of reducing CO_2 emissions is over $1,700 per ton in 2005. The second policy for comparison is the income tax credit of up to $3,400 for hybrid vehicle purchases. Beresteanu and Li (2009) estimate that the cost of reducing gasoline consumption is about $1.80 per gallon and the cost of reducing CO_2 emissions is $177 per ton. Thus, the unit cost estimates of reducing gasoline consumption for both programs are comparable to the cost of the Cash-for-Clunkers program. However, for reducing CO_2 emissions, the tax credit for ethanol is clearly dominated by the other two programs.

6. Conclusion

As part of the stimulus effort, the Cash-for-Clunkers program was so popular that it exhausted its original allocation of $1 billion within one week despite initial projections that the program would last three months. Nevertheless, while many considered the program to be a great success as a short-term stimulus measure, critics argued that the increased sales observed during the program period could be merely borrowed from immediate future months so that even the short-term effect on vehicle sales may not have been significant. Many have also raised doubts over the potential impact of the program on energy consumption and the environment.

Using a difference-in-differences approach with Canada as the control group, we have examined program effects on vehicle sales for different time-horizons as well as its impacts on pollutant emissions and gasoline consumption. Our analysis offers rather bleak evidence on the overall performance of the program. We find that a large portion of vehicles sold under the program was a result of demand switching from months surrounding the program: although the program increased vehicle sales by 0.36 million during July and August, the net effect on sales became practically zero by end of 2009. Furthermore, if the program were to be judged as an environmental program, the implied costs of reducing gasoline consumption and CO_2 emissions are quite high: the best-case scenario suggests a cost of over $91 in government expenditure for each ton of CO_2 avoided and almost 90 cents for each gallon of reduced gasoline consumption.

These evaluations of the program reflect the inherent difficulty of using a single policy to simultaneously accomplish multiple objectives. It would be important to examine whether alternative program designs would improve effectiveness and social welfare. This is out of the scope of our static framework since a structural model would be needed that incorporates both new and used vehicle markets. Nevertheless, some observations regarding program design can be made. First, given the unexpected popularity of the program and the much shorter program period than projected, it should be possible to achieve better environmental outcomes without hindering the stimulus effects by increasing the fuel economy requirements for new vehicles. Second, our analysis shows that about 45 percent of program expenditure was spent on consumers who would have purchased a new vehicle even in the absence of the program. This speaks to the challenge of isolating potential buyers who would not otherwise have purchased a new vehicle. In addition, the short-lived effect on sales implies that the intertemporal substitution occurred over a rather short time horizon. To the extent that the vehicle scrappage rate varies with vehicle attributes (such as class, size or fuel economy) and new vehicles are purchased to replace used vehicles, setting age thresholds based on the attributes of used vehicles could improve targeting and pull demand from a more distant future.

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Figures and Tables

Figure 1. Timeline of the Cash-for-Clunkers Program

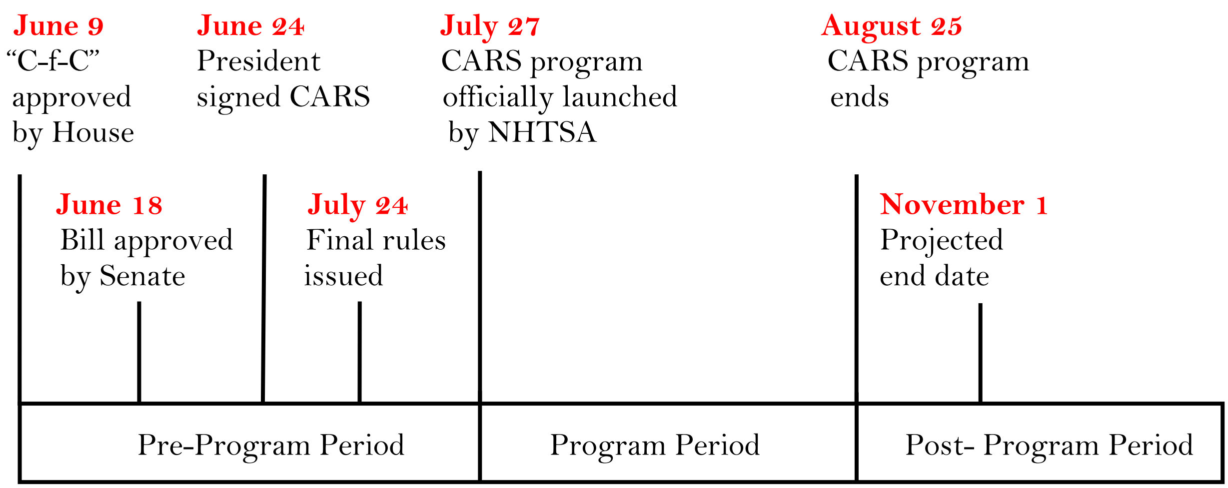
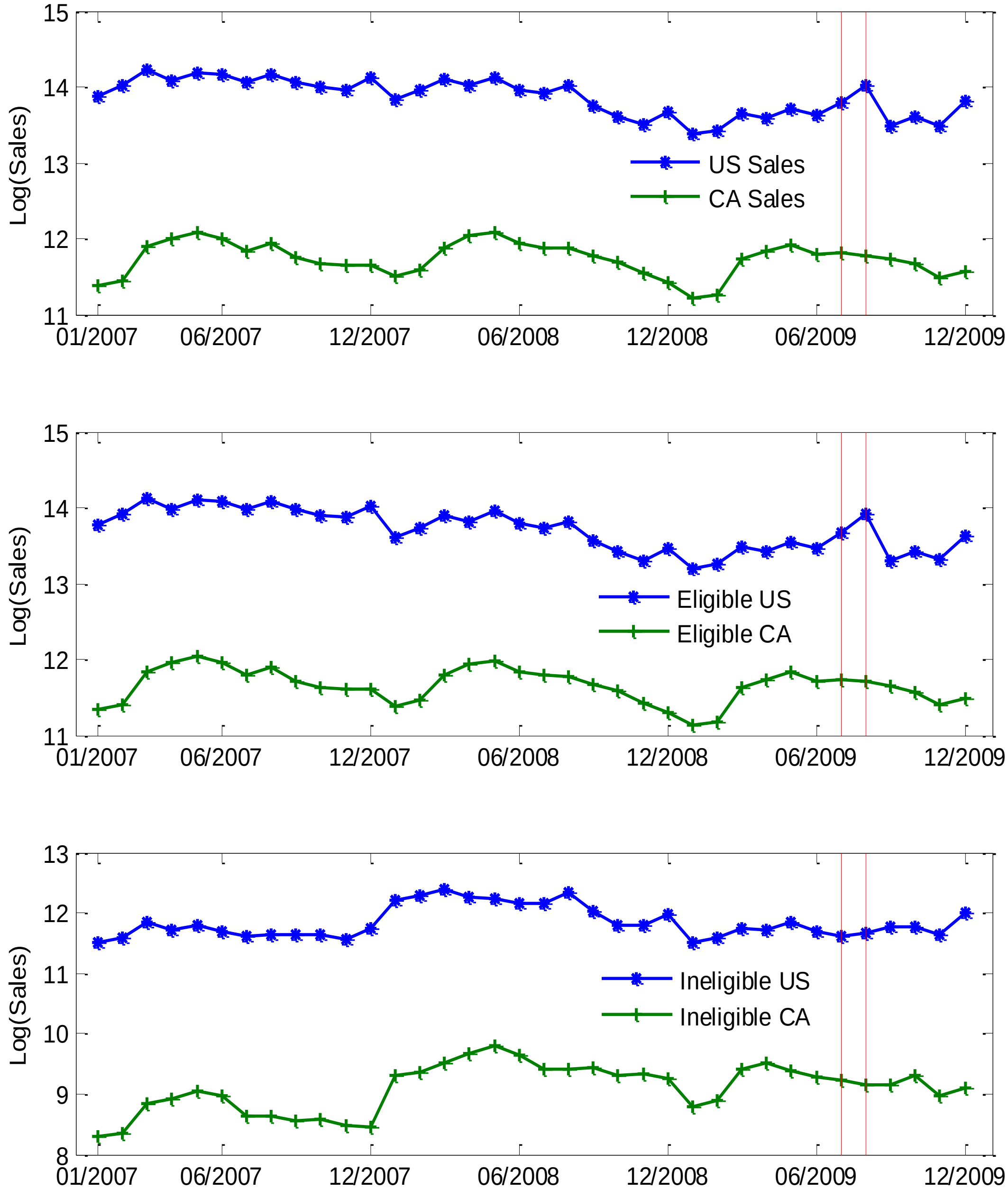
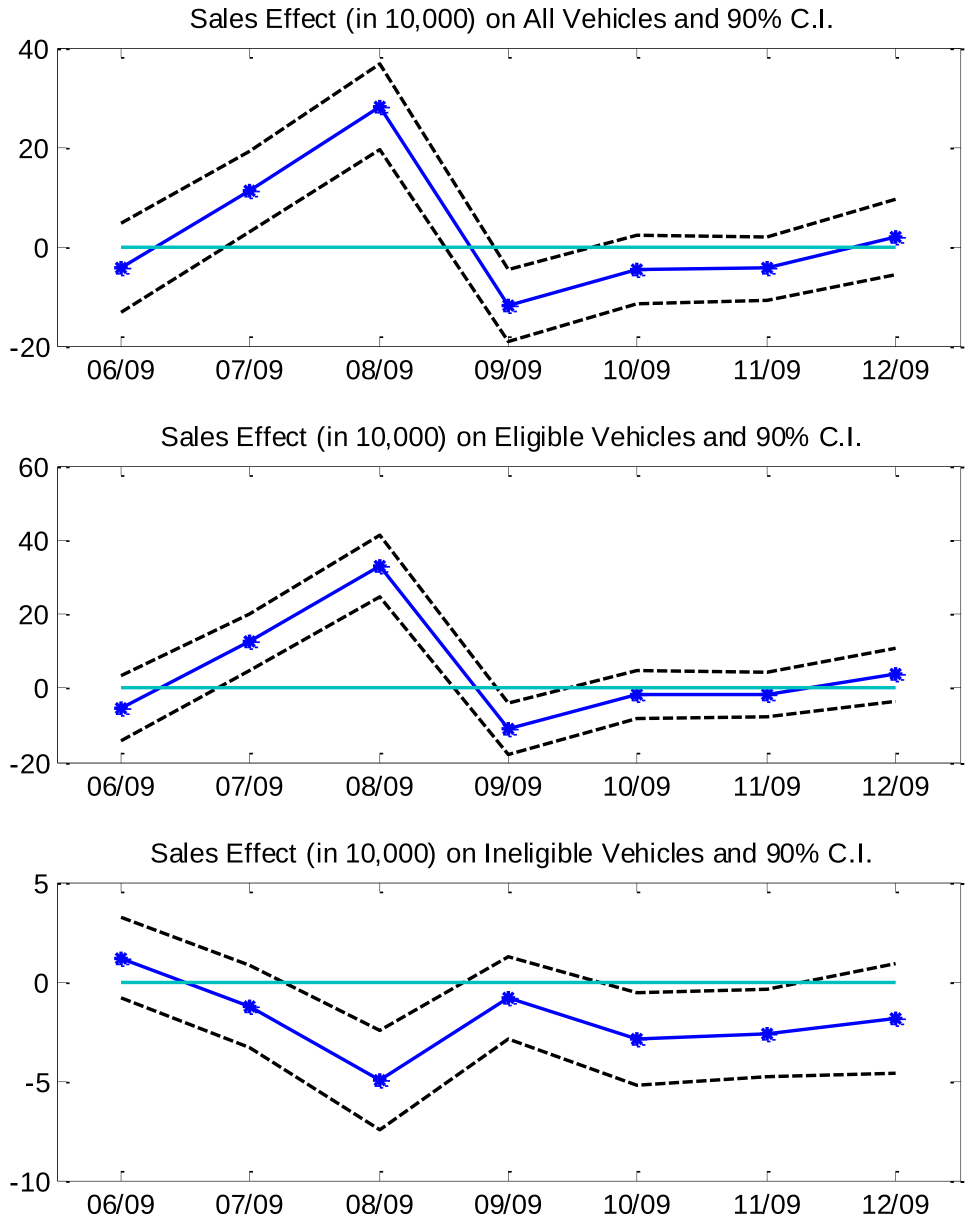


Figure 2. Monthly New Vehicle Sales in the United States and Canada from 2007 to 2009



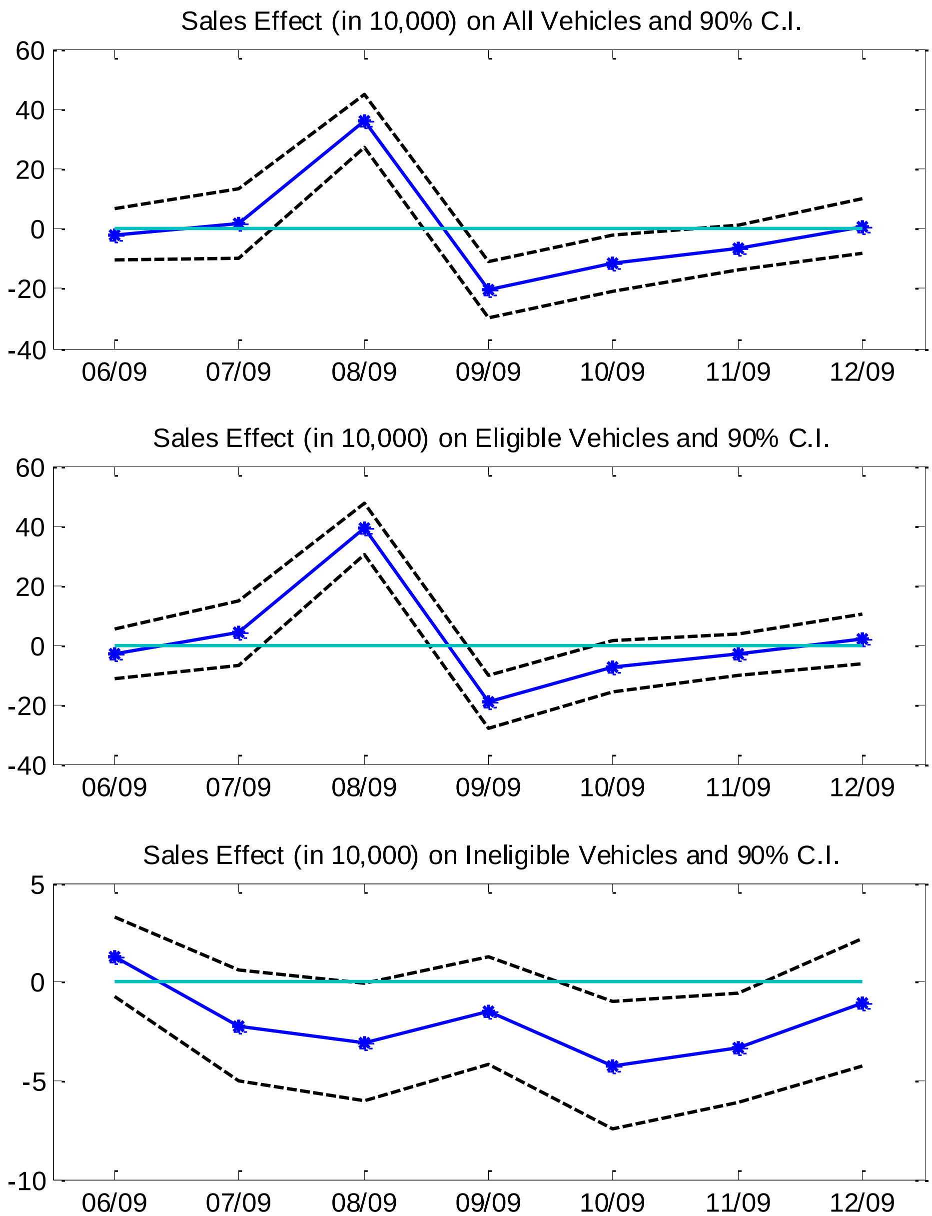
Note: The plots show total monthly sales in logarithm for all, eligible, and ineligible vehicles.

Figure 3. Sales Effect over Time Using the Full Sample



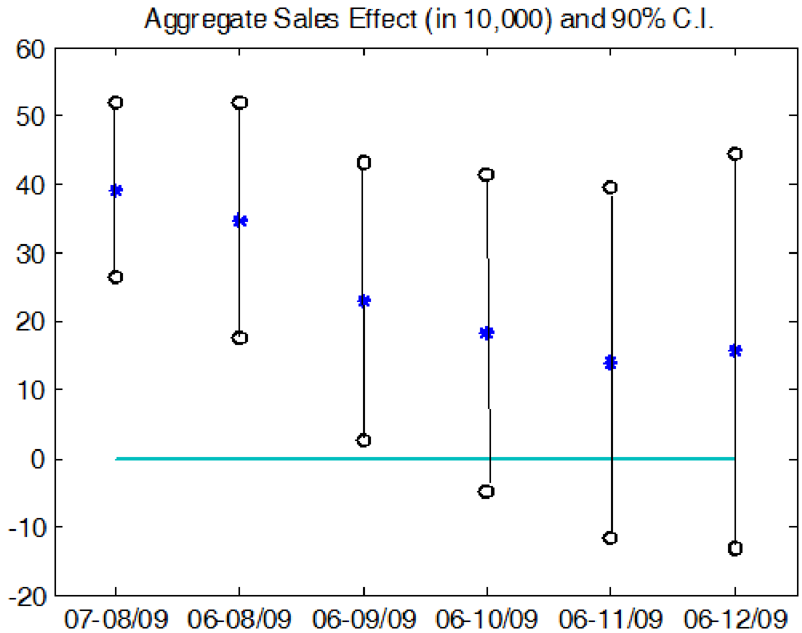
Note: The plots show the program effect on vehicle sales from June to December of 2009. The estimates are based on parameter estimates in Table 5 using the full sample. The 90% confidence intervals are estimated by bootstrap.

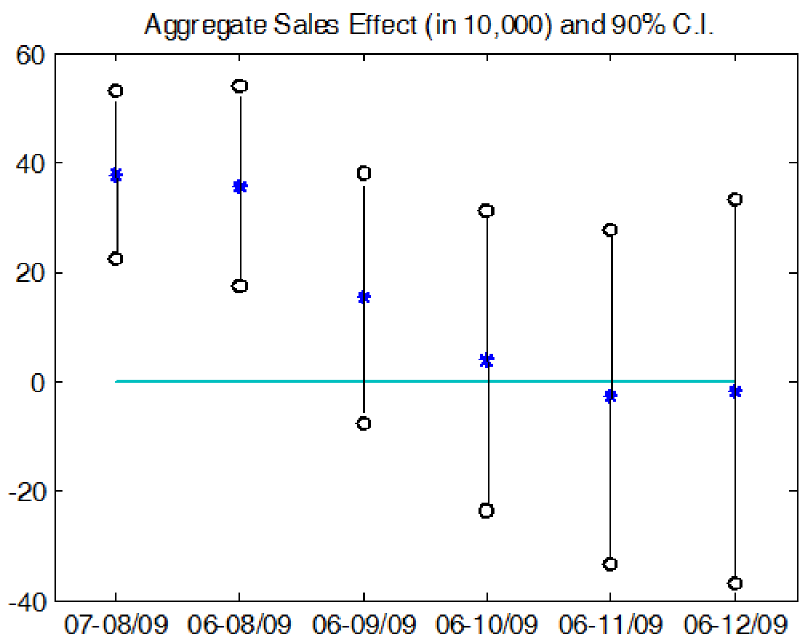
Figure 4. Sales Effect over Time Using the Short Pre-Program Sample



Note: The plots show the program effect on vehicle sales from June to December of 2009. The estimates are based on parameter estimates in Table 5 using the smaller sample. The 90% confidence intervals are estimated by bootstrap.

Figure 5. Aggregate Sales Effect over Different Time Horizons





Note: The top figure is based on estimates from the full sample while the bottom figure is based on the short pre-program sample. The 90% confidence intervals are constructed using bootstrap.

Table 1A. Rebate Eligibility Requirements

Trade-in Vehicle	• Is in drivable condition • Has been both continuously insured, consistent with the laws of your State, and continuously registered to the same owner for at least one year immediately prior to the trading-in of your vehicle under the CARS program • Manufactured less than 25 years before the date of trade (i.e., before mid- to late- 1984) and, in the case of category 3 trucks, not later than model year 2001 • Has a combined MPG of 18 or less (this does not apply to category 3 trucks, i.e., very large pickup trucks and cargo vans)
New Vehicle (Purchased or Leased)	• Is new (i.e., legal title has not been transferred to anyone) • Has manufacturer's suggested retail price of $45,000 or less

Table 1B. Rebate Amounts

Incentive Amounts					
If the type of new vehicle you want is a…	**The combined MPG* of the new vehicle must be…**	**The type of vehicle you trade-in must be a…**	**Amount of Incentive**		
			If the difference in combined MPG between new vehicle and trade-in vehicle is…	**The incentive is…**	
Passenger Automobile • All passenger cars	At least 22 MPG	Passenger car, category 1 or category 2 truck	4-9 MPG	3500	
			10 MPG or more		4500
Category 1 Truck† • All SUVs w/ GVWR <= 10,000 lbs • All pickups w/ GVWR < 8,500 lbs & wheelbase <= 115 inches • Passenger vans and cargo vans w/ GVWR < 8,500 lbs and wheelbase <= 124 inches	At least 18 MPG	Passenger car, category 1 or category 2 truck	2-5 MPG	3500	
			5 MPG or more		4500
Category 2 Truck† • Pickups w/ GVWR <= 8,500 lbs & wheelbase > 115 inches • Passenger vans and cargo vans w/ GVWR <= 8,500 lbs and wheelbase > 124 inches	At least 15 MPG	Category 2 truck	1 MPG	3,500	
			2 MPG or more		4,500
		Category 3 truck	NA‡	3,500	
Category 3 Truck† • Trucks w/ GVWR 8,500 – 10,000 lbs that are either pickup trucks with cargo beds 72” or longer or very large cargo vans	NA‡	Category 3 truck	NA‡ However, the new vehicle must be similar in size or smaller than the trade-in	3,500	

* MPG requirements are based on EPA’s combined city/highway rating
† GVWR = Gross Vehicle Weight Rating

‡ Not applicable: Category 3 trucks do not have EPA MPG ratings

Table 2. Summary Statistics of Vehicle Data

	No. of Observations			Monthly Sales per Model		
	Eligible	Ineligible	All	Eligible	Ineligible	All
United States	6,394	2,742	9,136	5,254	1,878	4,241
Canada	5,476	2,202	7,678	774	157	597
	Average Vehicle Price			**Average MPG**		
	Eligible	Ineligible	All	Eligible	Ineligible	All
United States	24,780	43,678	30,452	23.28	18.01	21.70
Canada	24,071	42,920	29,477	22.62	17.96	21.28

Note: The table provides statistics for variables at the country-year-nameplate (i.e., model) level for years from 2007 to 2009.

Table 3. Trade-in and New Vehicles Participating in the Program

	Cars		Trucks		All	
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Panel 1: Trade-in Vehicles						
MPG	17.55	1.01	15.50	1.75	15.81	1.81
Age	15.60	4.20	13.45	3.99	13.78	4.10
VMT	140,833	53,940	150,432	53,284	148,982	53,494
Observations	99,624		559,776		659,400	
Panel 2: New Vehicles						
MPG	27.96	5.21	20.73	3.17	25.00	5.73
Rebate ($)	4,224	451	4,200	462	4,214	456
Observations	388,809		270,591		659,400	

Note: The program included 678,359 transactions (www.cars.gov). In order to be consistent with our analysis of the new vehicle market, we delete 18,959 transactions, which include 2,278 category 3 new vehicles, 6,169 leases, and 10,512 observations with data errors (e.g., out-of-range MPG data). The total rebate amount for the remaining 659,400 transactions is about \$2.78 billion, compared to a total program payment of \$2.85 billion.

Table 4. Testing for Common Trends

		Full Sample		Short Sample	
		Est.	S.E.	Est.	S.E.
Eligible Vehicles in the United States	Feb	0.018	0.123	0.078	0.119
	March	-0.024	0.111	0.024	0.107
	April	-0.009	0.113	0.034	0.108
	May	-0.008	0.120	-0.025	0.114
Ineligible Vehicles in the United States	Feb	-0.001	0.144	-0.008	0.139
	March	-0.057	0.129	-0.043	0.125
	April	-0.018	0.134	-0.018	0.128
	May	-0.163	0.142	-0.147	0.136
R-squared		0.965		0.975	
F-test stat. and p-value for eligible:		0.040 (0.997)		0.272 (0.896)	
F-test stat. and p-value for ineligible:		0.548 (0.701)		0.474 (0.755)	

Note: These are estimation results for equation (2). The dependent variable is the logarithm of vehicle sales. The number of observations is 16,776 in the full sample and 13,976 in the short pre-program sample. Unreported control variables include: dollars per mile, model fixed effects, country-specific seasonality by eligibility type, and year-month common trends by eligibility type.

Table 5. Difference-in-Differences Regression Results

		Full Sample		Short Sample	
	Variable	**Est.**	**S.E.**	**Est.**	**S.E.**
Eligible Vehicles in the United States	June	-0.114	0.069	-0.066	0.070
	June*|ΔGPM|	0.064	0.057	0.036	0.057
	July	-0.080	0.073	-0.163	0.081
	July*|ΔGPM|	0.300	0.059	0.276	0.059
	August	0.104	0.074	0.202	0.078
	August*|ΔGPM|	0.310	0.071	0.282	0.071
	Sept.	-0.106	0.079	-0.199	0.084
	Sept*|ΔGPM|	-0.101	0.078	-0.126	0.078
	Oct.	0.038	0.088	-0.029	0.095
	Oct.*|ΔGPM|	-0.093	0.078	-0.118	0.078
	Nov.	-0.012	0.082	-0.010	0.089
	Nov.*|ΔGPM|	-0.027	0.059	-0.059	0.060
	Dec.	0.092	0.104	0.088	0.112
	Dec.*|ΔGPM|	-0.056	0.078	-0.086	0.078
Ineligible Vehicles in the United States	June	0.121	0.122	0.110	0.118
	June*|ΔGPM|	-0.068	0.090	-0.031	0.090
	July	-0.148	0.122	-0.232	0.138
	July*|ΔGPM|	0.083	0.095	0.114	0.095
	August	-0.437	0.126	-0.333	0.148
	August*|ΔGPM|	0.154	0.099	0.190	0.100
	Sept.	-0.252	0.123	-0.316	0.131
	Sept*|ΔGPM|	0.352	0.089	0.384	0.090
	Oct.	-0.416	0.131	-0.520	0.146
	Oct.*|ΔGPM|	0.365	0.095	0.397	0.095
	Nov.	-0.394	0.151	-0.470	0.167
	Nov.*|ΔGPM|	0.333	0.118	0.371	0.118
	Dec.	-0.326	0.160	-0.293	0.179
	Dec.*|ΔGPM|	0.393	0.126	0.429	0.127
R-squared		0.946		0.956	

Note: These are estimation results for equation (1). The dependent variable is the logarithm of vehicle sales. The number of observations is 16,776 in the full sample and 13,976 in the short pre-program sample. The full set of control variables described in equation (1) is included in the regressions: dollars per mile, model fixed effects, country-specific seasonality by eligibility type, and year-month common trends by eligibility type. |ΔGPM| is the absolute difference between the GPM of the vehicle and the eligibility requirement: the farther away an eligible vehicle's MPG is away from the requirement, the larger it is. This is true for ineligible vehicles as well.

Table 6. Program Effects during June- December 2009 in the United States

		Full Sample			Short Pre-program Sample		
	Observed	**Simulated**	**Difference**	**S.E.**	**Simulated**	**Difference**	**S.E.**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Panel 1: Effect on Vehicle Sales							
June	828,286	868,698	-40,412	49,812	846,939	-18,653	48,123
July	970,490	869,649	100,841	45,941	956,515	13,975	65,022
August	1,231,137	966,680	264,457	51,017	887,567	343,570	54,103
September	719,795	845,336	-125,541	46,885	935,406	-215,611	59,354
October	810,066	863,569	-53,503	46,232	940,613	-130,547	63,408
November	719,140	766,726	-47,586	41,169	788,512	-69,372	48,809
December	992,053	971,166	20,887	52,427	982,932	9,121	62,708
July-August	2,201,627	1,836,329	365,298	73,631	1,844,082	357,545	88,711
June-December	6,270,967	6,151,824	119,143	177,277	6,338,484	-67,517	219,782
Panel 2: Effect on Vehicle MPG							
July-August	23.37	22.72	0.65	0.08	22.77	0.60	0.09
June-December	22.75	22.52	0.23	0.06	22.57	0.17	0.07
Panel 3: Effect on Vehicle gallons per 100 miles (GPM)							
July-August	4.47	4.58	-0.11	0.01	4.56	-0.11	0.02
June-December	4.59	4.63	-0.04	0.01	4.62	-0.03	0.01

Note: Simulated outcomes are obtained under the counterfactual without the Cash-for-Clunkers program.

Table 7. Program Effects on Sales for the Industry and Automakers

	Full Sample				Short Pre-program Sample		
	Observed	Simulated	Difference	S.E.	Simulated	Difference	S.E.
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Panel 1: Effects during July and August 2009							
Industry	2,201,627	1,836,329	365,298	73,631	1,844,082	357,545	88,712
GM	405,394	340,830	64,564	13,740	341,794	63,600	16,452
Ford	318,573	272,893	45,680	10,647	274,668	43,905	13,023
Chrysler	181,846	167,260	14,586	6,654	167,834	14,012	8,197
Toyota	402,317	308,171	94,146	13,369	311,358	90,959	16,003
Honda	276,003	214,177	61,826	9,311	215,937	60,066	11,062
Nissan	176,931	142,366	34,565	5,898	142,588	34,343	6,971
Panel 2: Effects during June to December 2009							
Industry	6,270,967	6,151,824	119,143	177,277	6,338,484	-67,517	219,782
GM	1,189,728	1,170,326	19,402	33,625	1,204,692	-14,964	41,657
Ford	963,950	961,454	2,496	27,283	989,441	-25,491	33,727
Chrysler	511,564	523,697	-12,133	14,947	536,994	-25,430	18,782
Toyota	1,130,300	1,076,671	53,629	34,431	1,119,265	11,035	42,592
Honda	720,035	686,146	33,889	21,325	709,295	10,740	26,032
Nissan	479,840	461,616	18,224	13,616	475,493	4,347	16,773

Table 8. Remaining Lifetime VMT for Cars and Light Trucks

Age	Survival Probability		Annual VMT		Remaining VMT	
	Cars	Trucks	Cars	Trucks	Cars	Trucks
1	0.9900	0.9741	14231	16085	152143	179957
2	0.9831	0.9603	13961	15782	139449	168657
3	0.9731	0.9420	13669	15442	126467	155299
4	0.9593	0.9190	13357	15069	114097	142874
5	0.9413	0.8913	13028	14667	102382	131380
6	0.9188	0.8590	12683	14239	91312	120796
7	0.8918	0.8226	12325	13790	80865	111100
8	0.8604	0.7827	11956	13323	70988	102226
9	0.8252	0.7401	11578	12844	61623	94114
10	0.7866	0.6956	11193	12356	52673	86687
11	0.7170	0.6501	10804	11863	44065	79877
12	0.6125	0.6040	10413	11369	37538	73604
13	0.5094	0.5517	10022	10879	33530	67853
14	0.4142	0.5009	9633	10396	30294	63406
15	0.3308	0.4522	9249	9924	27624	59441
16	0.2604	0.4062	8871	9468	25339	55918
17	0.2028	0.3633	8502	9032	23319	52783
18	0.1565	0.3236	8144	8619	21440	49984
19	0.1200	0.2873	7799	8234	19639	47497
20	0.0916	0.2542	7469	7881	17813	45264
21	0.0696	0.2244	7157	7565	15867	43277
22	0.0527	0.1975	6866	7288	13726	41459
23	0.0399	0.1735	6596	7055	11262	39818
24	0.0301	0.1522	6350	6871	8278	38271
25	0.0227	0.1332	6131	6739	4624	36756
26	0	0.1165	0	6663	0	35259
27		0.1017		6648		33651
28		0.0887		6648		31900
29		0.0773		6648		29927
30		0.0673		6648		27693
31		0.0586		6648		25160
32		0.0509		6648		22247
33		0.0443		6648		18964
34		0.0385		6648		15142
35		0.0334		6648		10775
36		0.0290		6648		5772

Table 9. Cost-Effectiveness Analysis

	Total Reductions		**Cost ($) w/ Co-benefit**		**Cost ($)w/o Co-benefit**	
	Gasoline (mil gallons) (1)	CO2 (mil tons) (2)	Gasoline (per gallon) (3)	CO2 (per ton) (4)	Gasoline (per gallon) (5)	CO2 (per ton) (6)
Panel 1: Lifetime VMT (Full Sample)						
Case 1: No rebound effect	2930.8	28.4	0.88	90.9	1.02	105.5
Case 2: Rebound elasticity = 0.1	2857.6	27.7	0.9	93.3	1.05	108.2
Case 3: Rebound elasticity = 0.5	2564.6	24.9	1.01	103.9	1.17	120.6
Panel 2: Adjusted VMT (Full Sample)						
Case 4: No rebound effect	1099.5	10.7	2.35	242.4	2.73	281.3
Case 5: Rebound elasticity = 0.1	1084.6	10.5	2.38	245.8	2.77	285.2
Case 6: Rebound elasticity = 0.2	1020.6	9.9	2.53	261.2	2.94	303
Panel 3: Lifetime VMT (Smaller Sample)						
Case 7: No rebound effect	2855.2	27.7	0.91	93.4	1.05	108.3
Case 8: Rebound elasticity = 0.1	2791.5	27.1	0.93	95.5	1.07	110.8
Case 9: Rebound elasticity = 0.5	2536.5	24.6	1.02	105.1	1.18	121.9
Panel 4: Adjusted VMT (Smaller Sample)						
Case 10: No rebound effect	1019.5	9.9	2.54	261.4	2.94	303.4
Case 11: Rebound elasticity = 0.1	1001.2	9.7	2.58	266.2	3	308.9
Case 12: Rebound elasticity = 0.2	924.4	9	2.8	288.3	3.25	334.6

Note: Panels 1 and 2 are based on the estimation results from the full sample while panels 3 and 4 are based on the short pre-program sample. Panels 1 and 3 compare the lifetime gasoline consumption of new vehicles sold June-December of 2008 with the lifetime gasoline consumption of (less fuel efficient) new vehicles that would have been sold June-December without the program plus gasoline consumption from the trade-in vehicles during their remaining lifetime. Panels 2 and 4 adjust the VMT of new vehicles under the counterfactual scenario so that the total VMT under the two scenarios are the same.