Impacts of Eco-driving on Passenger Vehicle Use and Greenhouse Gas Emissions

Technical Background Document

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Technical Background Document on Impacts of Eco-driving Based on a Review of the Empirical Literature

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Study Selection

We focused on recent studies in the U.S. in real-world conditions. There have been few eco-driving training programs or educational campaigns in the U.S., and no studies measuring their impact that meet our criteria. However, an emerging body of research examines the effects of in-vehicle devices and mobile apps (that is, applications on smartphones) that provide real-time feedback on driving behavior and energy use. In part because these technologies are still new, only one large-sample, statistically rigorous study examining the impact of such devices on driver behavior is available so far (Kurani et al., 2013). Two smaller pilot studies help demonstrate potential driver response, but do not have sufficient sample size to assess significant response (Martin et al., 2013; Boriboonsomin et al., 2010). Other studies have focused on the range and efficacy of different types of user interfaces (Stillwater, Woodjack, & Nicholas, 2013; Stillwater, Davies, & Kurani, 2013).

Although European studies examine the effects of a broader set of eco-driving strategies, the results are not likely to apply in the U.S. context. First, their vehicles often use different technology, such as diesel-powered engines rather than gasoline-powered engines. Diesel engines have less variation in fuel economy, and thus potential behavior-induced savings, than gasoline engines (de Vlieger et al., 2000). Second, differing attitudes and a longer history of promoting eco-driving tactics in Europe make the reception of eco-driving programs different in Europe than in the U.S. While the opportunity for improvement among U.S. drivers may be greater, convincing drivers to change may require more outreach.

Effect Size, Methodology, and Applicability Issues

In all three studies cited, researchers installed tracking devices in participants' personal vehicles that recorded second-by-second driving data, such as acceleration, speed, and fuel consumption, and provided visual feedback displays to drivers. Data were collected for one month with the feedback display off and then one month with it on. The researchers then compared the two sets of data (off versus on) to deduce the effect of the feedback on driving behavior.

In the largest study, Kurani et al. (2013) recruited 118 drivers residing in four different cities along the I-80 corridor between San Francisco, California and Reno, Nevada from a randomly drawn list of qualifying households affiliated with AAA. While participating households were somewhat older and higher-income than the general population in the areas studied, their trip profiles were similar to the general population. By contrast, the two smaller studies used convenience samples, with 20 drivers participating in Boriboonsomin et al.'s (2010) Southern California study, who had self-selected after having participated in a prior research project, and 18 drivers who lived or worked in proximity to researchers in Berkeley, CA (Martin et al., 2013). Both of the smaller studies installed the same off-the-shelf feedback device, the Eco-way Navigator. Kurani et al. (2013) installed the DrewTech DashDaq device, and also experimented with three different types of feedback displays randomly assigned to study participants – one showing numerical display of instantaneous and trip-average MPG, another an animated acceleration/deceleration bar, and a third using shrubbery icons to characterize current fuel-economy level.

Martin et al. (2013) compared overall average miles per gallon for each driver in the study during the period before the feedback was displayed and the period with the feedback displayed. They did not adjust for differences in the types of trips or other changes that may have occurred between the first and second month of observation. They found that average fuel economy improved for 11 drivers and worsened for 6 during the month with the feedback display versus the prior month. The change for individual drivers ranged from -25.7% to +25.0% (or -4.8% to +8.7% excluding two outliers), with an average of +0.8% improvement overall, but not statistically significant among the sample size of 18 drivers.

Boriboonsomin et al. (2010) also compared overall miles per gallon with and without the feedback display, but first adjusted the second-by-second driving data based on the theoretical vehicle specific power for each participating vehicle and aggregated over each driver's entire record of data (to help normalize the effects of road grade, weight, and rolling and drag forces), and then calculated the average fuel economy for the portions of driving that were highway versus city driving. They found that for highway driving, due to receiving real-time feedback, average changes in fuel economy for individual drivers ranged from -12% to +13%, with an average of +1% across all drivers. For city driving, average changes in fuel economy for individual drivers ranged from -5% to +24%, with an average of +6% across all drivers, though neither improvement was statistically significant among the sample size of 20 drivers.

Kurani et al. (2013) examined overall miles per gallon among each of the 140 driver-vehicle combinations for which they had collected data with and without the feedback display. They used a mixed-effects regression model to isolate the effect of the display, while controlling for actual road grade and weather conditions, finding a statistically significant overall improvement of +2.7% across all participants. They also identified five distinct trip types through a cluster analysis of the logged data and found substantial differences in the economy gains in each, ranging from no effect to a +9% improvement (see Table 1). After accounting for the mix of trip types in the periods with and without the feedback device, the effect of the feedback display was a +2.2% improvement across all participants. They found that the behavior change with the biggest overall impact on fuel economy was a reduction in median speed (accounting for a +2.4% improvement in fuel economy overall), followed by a tempered acceleration rate (accounting for a +1.0% improvement), with less impact from drivers' top speeds and deceleration rates (that is, hard braking). In addition, they found that female drivers improved much more than males, with a +5.0% average change among women versus +1.9% among men.

The efficacy of the three different type of feedback displays, randomly assigned to each participant, ranged from +1.6% to +2.9%, but with overlapping confidence intervals (and so no statistically significant difference between them was found). Because of heterogeneity in drivers' priorities (e.g. safety, speed, saving gas, etc.) and driving patterns, the authors note that better tailoring the feedback display to different driver groups could prove more effective, with one group whose goals matched the display type they were shown achieving 22% improvement in fuel economy. The authors estimated that matching all of the participants with feedback displays suited to their goals would have resulted in a 9.2% improvement in overall fuel economy.

Table 1. Change in Fuel Consumption Using an In-Vehicle Feedback Device, for Five Trip Types, from Kurani et al. (2013)

Trip Type*	**Average distance (miles)**	**Average speed (mph)**	**Maximum speed (mph)**	**Portion of total trips recorded**	**% reduction in fuel consumption with activated feedback device**
Milk Run	3	11	23	34%	0%
Short Arterial	11	19	35	34%	1%
Cross-Town	23	16	35	6%	9%**
Inter-City	29	27	50	15%	1%
Regional	101	39	55	10%	3%**

* Kurani et al. (2013) categorized trips into five types based on a cluster analysis that accounted for the total distance, average speed, maximum speed, and speed variation of each trip. Attributes of cluster centroids are shown here, along with the names Stillwater & Kurani (2012) ascribed to each.

** Significant at $p < 0.05$.

Results from the three selected U.S. studies may not be applicable in other contexts. The studies address a narrow set of strategies relative to the wide range of possible programs and interventions, and they have relatively small sample sizes that may be biased to include participants predisposed to changing their behavior (e.g. selection bias). Short-term behavior change as measured in these studies may not translate into sustained behavior change. Different vehicle makes and models may require somewhat different eco-driving strategies to maximize efficiency, with today's vehicles different from older ones, and future vehicles different from current ones. In addition, the type of road, road infrastructure design, terrain, weather, and traffic conditions in which people do most of their driving influence the extent of savings that are possible. As shown in Kurani et al. (2013), different types of feedback displays may elicit different types of response, depending on individual drivers' preferences, driving goals, and typical driving patterns.

Related Evidence

Prior to 2000, the most recent U.S. studies on the effects of eco-driving programs were conducted in the 1970s, when there was general interest in fuel-saving strategies. We excluded these previous studies from our analysis because vehicle technology and in-vehicle driver aids have changed substantially since then. For instance, fuel-saving strategies such as warming up the engine prior to driving provided a benefit for older engines, but is no help in modern ones (Barkenbus, 2010).

Even with differing technologies, earlier studies found approximately the same amount of potential change in fuel savings as a result of driving-behavior change as do the more recent studies (see Table 2). In particular, a General Motors study in the 1970s found that drivers who were told to “minimize fuel consumption” achieved 10.4% improvement in fuel economy while those told to “use vigorous acceleration and deceleration” reduced fuel economy by 17.3% compared to those told to drive normally, a 28% spread; another GM study found “gentle driving” improved fuel economy by 11% while “hard driving” diminished it by 29%, each compared to “moderate driving,” for an overall spread of about 39% (Chang et al., 1976; Chang & Herman, 1980; both as cited in Greene, 1986).

Some different strategies also apply to hybrid and electric vehicles compared to those with conventional internal combustion engines. Regenerative-braking technology, for example, can help offset the energy consumed in stop-and-go conditions. In general, the tank-to-wheel energy use for plug-in hybrids is lowest per mile of city driving and highest for highway driving, the opposite as with conventional internal combustion engines (Raykin et al., 2012). Even so, softer acceleration and lower overall speeds are still best strategies for electric-powered vehicles (Bingham et al., 2012). In general, engine size, weight, and wind resistance imply differences for any given vehicle’s optimal cruising speed and response to other efficiency tactics.

Table 2. Potential Fuel Savings Resulting from Driving Behavior, 1970s versus 2000s in the U.S.

Study	Study year	Behavior comparison	Average effect	Range of effect	Sample size
GM (Chang et al. 1976, cited in Greene 1986)	1970s	"minimize fuel consumption" vs. normal	10%	NA	NA
		"use vigorous acceleration and deceleration" vs. normal	17%	NA	NA
GM (Chang and Herman 1980 cited in Greene 1986)	1970s	"hard driving" vs. "moderate"	29%	NA	NA
		"gentle driving" vs. "moderate"	11%	NA	NA
Reed 2005	2005	Aggressive vs. moderate driving	31%	Up to 37%	55-mile loop 15 times
		Cruise at 65mph vs. 75mph	12%	Up to 14%	50 mile stretch, once in each direction
Ford 2008	2008	Before vs. after 4-day hands-on eco-driving training	24%	6% to over 50%	48 drivers

There have been few eco-driving training programs or educational campaigns in the U.S., and no studies measuring their impact on driving that meet our criteria. The programs and analysis that do exist are summarized below.

The U.S. Department of Energy's Driver Energy Conservation Awareness Training (DECAT) program, operational from 1979 to 1980, included classroom and behind-the-wheel instruction on energy-saving techniques, focusing on drivers of government and private fleets, and train-the-trainer on site in Colorado. Greene (1986) reports fuel savings of 10% among program participants and among participants in spin-off state-level programs focused on driver training, often of fleet vehicles. Since then, one small study in California (n=104) measured ordinary drivers' self-assessments before and after viewing an eco-driving website (Martin et al., 2012). In contrast to a control group who did not view the website, the group who viewed the website reported slower highway cruising speeds, less idle time, and adjusting their driving behavior to improve fuel economy more often when surveyed three months after having viewed the website. Overall, 71% of those who had viewed the website reported that they made changes in their driving behavior afterwards, but actual changes were not measured. In addition, a 2008 pilot program in Denver, CO installed devices in 400 vehicles to track miles driven, idling time, fast starts, hard breaking, speeding, and fuel consumption over 7 months. Metrics were compiled on a website, where drivers could monitor their performance (see www.drivingchange.org and Driving Change, 2008). A press release reports a 10% improvement in fuel economy, in part from a 35% reduction in idling time, among study participants (Enviance, 2009).

Educational programs in Europe and Japan include training, advertising, incentives, and competition. Impacts of various programs are estimated to range from 5 to 50% improvement in fuel economy in the short-run and 3 to15% in the mid-term (International Transport Forum, 2007), with larger effects for programs incorporating follow-up. As an example of an academic study outside the U.S., Beusen et al. (2009) examined the longer-term change among drivers who enrolled in a training course in Belgium, using in-vehicle devices to monitor behavior (but not provide real-time feedback) for 10 drivers over a period of 10 months. This study found a statistically significant reduction in fuel consumption for 7 of the 10 drivers, and no significant change among the remaining 3 (Beusen et al., 2009). In addition, overall impacts diminished over time, with an average initial reduction of 6.7% that diminished by an average of 0.21% per week following the training (Degraeuwe & Beusen, 2013).

Another set of programs target drivers of specific fleets such as bus drivers and mail carriers. For instance, in Sweden, Wåhlberg (2007) found that eco-driving training for bus drivers resulted in a 2% reduction in fuel consumption 12 months after the training, which increased to 4% with the addition of an in-vehicle feedback device. Also in Sweden, Larsson and Ericsson (2009) examined the effect of installing a haptic feedback acceleration-advisory tool in mail carrier trucks. They found that strong acceleration was significantly reduced, but that this resulted in statistically significant fuel savings on only two of three mail carrier routes.

In summarizing the available evidence, Barkenbus (2010) concludes that the *potential* fuel savings if a driver successfully applies all eco-driving strategies may be about 25% of overall fuel consumption, but that the effect of a promotional intervention on *actual* behavior may result in about 10% in fuel savings in the short-run (soon after the training) and about 5% in the longer-run.

In addition to overall training and in-vehicle feedback, another set of eco-driving strategies focuses on speed management in particular. Speed can be controlled by road infrastructure design that limits likely maximums through geometry or other traffic calming elements. On existing roadways, policies for encouraging more moderate speeds include setting speed limits, enforcement of existing speed limits, and utilizing advanced technology to enforce maximum limits automatically (“active” speed management). Empirical evidence shows that higher speed limits are indeed associated with higher speeds (e.g. Retting & Cheung, 2008), and various forms of enforcement impact speed in enforcement areas (e.g. Retting et al., 2008; Vaa, 1997; Teed & Lund, 1993; Hauer et al., 1982). Farzaneh and Zietsman (2012) estimate the marginal increase in emissions associated with cars exceeding the speed limit at different thresholds. In particular, they estimate an average increase in CO_2 emissions of 3.9% for drivers going over the speed limit in a 65 mph zone and a 1.0% increase in a 60 mph zone in sample corridors in Texas.

However, the effect of enforcement on overall emissions is complex, since accelerating and decelerating through enforcement areas can outweigh the impact of reduced cruising speed (Farzaneh & Zietsman, 2012; Panis et al., 2006). In a similar way, traffic calming elements can have varying implications for emissions, depending on how and how much they slow traffic. For instance, in a Swedish study, Smidfelt Rosqvist (2000) estimated that speed humps reduce pollutants about ten times as much as junctions. In general, the goal of reducing the average speed must be balanced with the goal of reducing the variation in speed for optimal impact on emissions.

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