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How does on-road fuel economy vary with vehicle cumulative mileage and daily use?

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ABSTRACT

Understanding the fuel economy of vehicles in actual use has important implications for fuel economy, greenhouse gas emission and consumer information policies. This study explores how fuel economy varies with intensity of daily vehicle use, cumulative mileage, and ambient temperature. Using a unique longitudinal database, we quantify variations in fuel economy (miles per gallon or MPG) over time for the same vehicle. The database consists of more than 600,000 odometer and fuel purchase records, obtained from the "My MPG" section of the http://fueleconomy.gov website. Over 10,000 drivers reported their fuel purchases and vehicle usage, with an average of 36 fill-ups per vehicle. Multilevel models are used to analyze and compare relationships for conventional gasoline and hybrid vehicles. For gasoline vehicles, within-vehicle variation accounts for 23% total variation of fuel economy and 77% is between-vehicle variation. For hybrids, the equivalent proportions are 19% and 81%. On-road fuel economy increases nonlinearly with cumulative mileage, with nearly all of the increase occurring within the first few thousand miles. The estimated trend for hybrid vehicles is very different from that of conventional gasoline vehicles. Hybrids were found to have higher daily miles of use than conventional gasoline vehicles. Cold temperatures appear to have a greater effect on the fuel economy of hybrids than conventional gasoline vehicles.

1. Introduction

Fuel economy is a concern for policy makers, vehicle manufacturers and consumers. By regulating fuel economy and greenhouse gas emissions, governments are able to address energy security and environmental issues (Kleit, 2004; EPA, 2012). Auto manufacturers are required to meet standards but cost-effective fuel economy improvements can also boost sales (Huo et al., 2012; Jacobsen, 2013). Consumers need fuel economy information to make informed decisions about their vehicle purchase and use (Helfand and Wolverton, 2011).

Vehicle fuel economy is estimated by testing the new vehicles on pre-designed drive cycles in accordance with government procedures (EPA, 2013). Currently, five drive cycles designed by the Environmental Protection Agency, are used in fuel

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economy estimation (EPA, 2014). These cycles represent various driving conditions and driving styles, including city and highway driving, air conditioner use, cold starting and aggressive driving styles (EPA, 2013). Two different fuel economy numbers are generated from these tests (Kleit, 2004; EPA, 2012, 2014):

(1) Test cycle fuel economy values based on city and highway cycles only are used to enforce the Corporate Average Fuel Economy (CAFE) and greenhouse gas (GHG) emission regulations.
(2) Adjusted fuel economy (''label'') numbers based on all five cycles are used to inform consumers' car purchase and use decisions.

Although the label values are obtained through laboratory tests they are intended to represent what a typical motorist will experience in real-world driving. However, individual consumers' experience varies widely, as noted in the disclaimer that accompanies the label estimates (Lin and Greene, 2011; Dings, 2013; Mock et al., 2013; Greene et al., 2015). ''Actual results will vary for many reasons, including driving conditions and how you drive and maintain your vehicle'' (EPA, 2011). A number of studies have quantified the differences between the test cycle values and the fuel economy that consumers achieve in the real-world. These studies have typically found that test cycle fuel economy estimates are biased upward relative to on-road fuel economy by 15–20%. The label estimates are less biased but cannot accurately predict the fuel economy of any given motorist (McNutt et al., 1978, 1982; Schneider et al., 1982; Hellman and Murrell, 1984; Rykowski et al., 2005; Greene et al., 2006, 2015; Huo et al., 2011; Lin and Greene, 2011; Dings, 2013; Mock et al., 2013). Various factors, including driving conditions, driver behaviors, vehicle technologies and daily miles traveled influence on-road fuel economy. However, relatively little is known about how fuel economy varies for a given vehicle with usage intensity and cumulative mileage.

The objective of this study is to analyze the variability of fuel economy through statistical analysis of more than 600,000 odometer and fuel purchase records. The records analyzed in this study were voluntarily submitted by approximately 15,000 visitors to the ''My MPG'' section of the government website www.fueleconomy.gov. A vehicle's diary data includes a sequence of refueling events (fill-ups) with odometer readings, fuel quantities purchased and price paid (Greene et al., 2015). A few participants provided their odometer and fuel purchase diaries for over 20 years, with approximately 1000 valid observations. Other diaries contain only a few records. This longitudinal dataset facilitates temporal analysis of on-road fuel consumption and can help answer questions about the variability of an individual vehicle's MPG over time with intensity of daily vehicle use, vehicle age, cumulative mileage, and temperature.

We use a multilevel modeling approach to analyze the My MPG data with special attention to differences between conventional gasoline and hybrid vehicles. This approach takes account of heterogeneity in the magnitudes of associations by estimating a set of coefficients and an intercept for each group of observations, i.e., the set of fill-ups for a given vehicle, or the set of vehicles in one state. Of particular interest are the potentially non-linear relationships between on-road fuel economy and the intensity of vehicle use, cumulative mileage, and ambient temperature. We use a combination of theory, previous empirical research and Generalized Additive Modeling (GAM) to select appropriate functional forms for each of the three variables.

2. Literature review

2.1. Fuel economy test

Fuel economy (MPG-ratings) in the US are estimated under laboratory-controlled conditions using pre-designed driving cycles (EPA, 2013). The Federal Test Procedure (FTP) cycle (often called EPA75) simulates city driving conditions while the Highway Fuel Economy Driving Schedule (HWFET) represents free-flow traffic conditions. By statute, a (0.55/0.45) weighted harmonic mean of the two tests is used to determine manufacturers' compliance with CAFE and greenhouse gas regulations. Prior to 2008, only the FTP and HWFET were used for fuel economy labeling. Beginning with 2008 models, the values used for fuel economy labeling were calculated based on five test cycles to better reflect real-world driving conditions and behavior. The additional tests are the US06 (reflecting higher speed and acceleration), SC03 (reflecting air conditioner use in hot weather) and C-FTP (reflecting cold starting in cold ambient temperatures). Calculation of fuel economy for the purpose of regulatory compliance is still based on the two (FTP and HWFET) drive cycles.

No single drive cycle or combination of drive cycles can accurately represent the behavior and driving conditions of each and every individual driver (Liu et al., 2016). Using a data base of over 3000 individual drivers' fuel economy estimates, Greene et al. (2006) found that 90–95% of the values were within ±7 mpg (approximately ±33%) of a vehicle's label mpg. Using a larger sample of over 67,000 individual estimates, Greene et al. (2015) calculated a two-standard deviation interval around label mpg estimates of ±10 mpg for gasoline vehicles with an average label value of 24 mpg. In general, driving cycles are not designed to accurately predict individual driver's fuel economy but rather to provide consistent and repeatable methods for measuring the emissions and energy efficiencies of different vehicles that bear a stable relationship to average real-world performance. Cycles have been designed to feature local driving conditions, such as the New York City Cycle (NYCC) and the California Air Resources Board's LA92. Other nations have developed their own cycles, such as Europe's ECE R15 and EUDC, and Japan's JC08. Barlow et al. (2009)provide a comprehensive review of worldwide driving cycles.