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Are potential reductions in CO_2 emissions via hybrid electric vehicles actualized in real traffic? The case of Japan

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ABSTRACT

The number of private passenger hybrid electric vehicles (HEVs) in use in Japan has increased rapidly since 2009. One of the advantages of HEVs over conventional passenger vehicles lies in the higher fuel economy obtained by recent technological innovations, which helps reduce carbon dioxide (CO_2) emissions from transport. However, are the potential reductions in CO_2 emissions via HEVs actualized in real traffic in Japan? To answer this question, this study estimates the regional gap between on-road fuel economy and fuel economy in the regulated test procedures (test fuel economy) of HEVs and regional direct rebound effects of HEV use during 2010–2013. To estimate the direct rebound effects, a methodological framework of the Modified Laspeyres Index (MLI) decomposition is proposed to quantify the contribution of kilometers traveled per vehicle to aggregate the differences between CO_2 emissions per HEV and those per standard/small vehicle. The results show that the potential reductions in CO_2 emissions offered by the higher test fuel economy of HEVs have been offset markedly by the deterioration in test fuel economy and the direct rebound effects in real traffic over the period. An increase in fuel prices by implementing a fuel tax increase would be one method to improve the on-road fuel economy of HEVs and reduce the direct rebound effects. However, equity policies would be required for urban and rural regions. The findings present helpful information to policymakers wishing to promote higher fuel economy vehicles to reduce CO_2 emissions from transportation.

1. Introduction

Carbon dioxide (CO_2) emissions in Japan amounted to 1.23 billion metric tons of CO_2 equivalent in 2013, an increase of 16% from the 1990 level, with the transport sector accounting for 18% of aggregate CO_2 emissions (GIO, 2015). CO_2 emissions from private passenger vehicles peaked in 2001 and have been on the decline since; nevertheless, these emissions were 42% higher in 2013 than the 1990 level, accounting for 48% of all CO_2 emissions from the transport sector. Thus, reducing CO_2 emissions from private passenger vehicles remains important for reducing CO_2 emissions from transport.

In Japan, private passenger hybrid electric vehicles (HEVs) were introduced into the market in 1997, and the number of such HEVs in use has increased rapidly, especially since 2009. HEVs, which have both an internal combustion engine and an electric motor, are expected to help lower CO_2 emissions compared with a conventional internal combustion engine vehicle because of improvements in fuel economy (vehicle kilometers traveled, VKT, per unit fuel consumed). This is achieved by the

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use of an electric motor when the vehicle is started, gearing to run at maximum efficiency, and the use of regenerative braking when the vehicle is stopping. However, are the potential reductions in CO_2 emissions offered by the higher fuel economy in the regulated test procedures (test fuel economy hereafter) of HEVs actualized in real traffic? The potential reductions in CO_2 emissions resulting from improvements in the fuel economy of HEVs might be offset by driver behavior (e.g., driving more) or actual driving conditions (e.g., traffic congestion). Schipper (2011) insisted that fuel economy technology is not the only factor that can yield significant reductions in CO_2 emissions; he pointed out that as long as the number of vehicles and VKT continue to keep creeping up, it will be difficult for technology alone to lower CO_2 emissions from the transport sector.

Test fuel economy has often been confused with the fuel economy that can be expected in real traffic (termed on-road fuel economy). Of the two, test fuel economy has been discussed most commonly (Schipper, 2011). Because test fuel economy may be larger than on-road fuel economy and the gap may be misunderstood, there are important ramifications for policies aimed at boosting fuel economy (Schipper, 2011).

Moreover, the direct rebound effects should be considered. Known as Jevons' paradox (Sorrell, 2009), these effects help explain why gains in the efficiency of energy consumption result in a simultaneous reduction in energy cost and increased energy consumption (Greening et al., 2000). In other words, the potential reductions in CO_2 emissions resulting from technical improvements in vehicle fuel economy would be diminished by the direct rebound effects. Greene et al. (1999) pointed out that the direct rebound effects are critical for the relevance of technological change as a strategy for solving the greenhouse gas problem in that their impact determines whether technological improvements in energy efficiency could reduce greenhouse gas emissions to any significant extent. UKERC (2007a) insisted that rebound effects are of sufficient importance to merit explicit treatment: failure to take account of rebound effects could contribute to shortfalls in achieving energy and climate policy goals. However, rebound effects are difficult to quantify and widely ignored by policymakers, while their magnitude is greatly disputed, even among economists who understand the mechanisms involved (UKERC, 2007a).

Understanding the abovementioned consequences of vehicle use in real traffic is important when investigating the contribution of HEV use to reductions in CO_2 emissions and for developing sound policies. VKT per HEV and on-road fuel economy, which primarily determine CO_2 emissions from vehicles, should be monitored alongside test fuel economy per HEV to estimate the gap between on-road and test fuel economy and the rebound effects of HEV use given other factors such as fuel price. However, little effort has been made to monitor and analyze both the vehicle use and the on-road fuel economy of light-duty passenger vehicles (Schipper, 2011). Moreover, the on-road performance of HEV use in regions that contain large metropolitan areas may differ from that in other regions.

One of the limitations of quantifying the on-road performance of HEV use could be attributed to the limited availability of statistical data. However, since 2009 in Japan, regional statistical on-road performance data on HEV use, including VKT and fuel consumption, have become available publicly as separate statistical data from those on standard/small private passenger vehicles (SSVs). Thus, we are now able to quantify the regional gap between the on-road and test fuel economy of HEVs and the regional rebound effects of HEV use through publicly available data under the same fuel price and other socioeconomic situations in a particular region and a particular year.

An index decomposition technique can be used to understand better the source of changes in aggregate energy efficiency in order to quantify the rebound effect (Sorrell, 2009). Index decomposition analyses help identify relevant factors that influence changes in an objective variable such as CO_2 emissions and to quantify the relative contributions of the changes in these factors (Mishina and Muromachi, 2012). Among the many index decomposition methods used, the Modified Laspeyres Index (MLI) decomposition generates more valid decomposition results than the other index decomposition methods because of the reasonable attribution and distribution of residual interaction terms (Mishina et al., 2011; Mishina and Muromachi, 2012). The MLI decomposition quantifies the contributions of relevant factors to aggregate differences between CO_2 emissions per HEV and those per SSV, with the results allowing us to estimate the direct rebound effects of HEV use.

This study quantifies the actualization of the potential reductions in CO_2 emissions offered by the higher test fuel economy of HEVs by estimating the gap between the on-road and test fuel economy of HEVs and the regional direct rebound effects of HEV use in Japan. The latter effects are estimated by using the elasticity of the contribution of VKT per vehicle to the aggregate differences between CO_2 emissions per HEV and those per SSV with respect to improvements in the on-road fuel economy of HEVs compared with those of SSVs given the same fuel unit price and other socioeconomic factors. A methodological framework of the MLI decomposition is then proposed to quantify the contribution of VKT per vehicle to the aggregate differences between CO_2 emissions per HEV and those per SSV. The statistical data used are available in the public domain over the period 2010–2013. Moreover, a policy for improving the on-road performance of HEV use is proposed.

2. Literature review

Studies have investigated the gap between the on-road and test fuel economy of passenger vehicles as a whole, but not that for HEVs. Schipper (2011) stated that the on-road fuel economy of vehicles sold in 2009 in Japan was around 27% lower than their test fuel economy. JAMA (2013) reported that the on-road fuel economy of gasoline-powered passenger vehicles in use was 31% lower than their test fuel economy (10.15 modes) in 2009 in Japan. Zachariadis (2006) pointed out that on-road fuel economy has been lower historically than test fuel economy and suggested that of all vehicle categories, on-road