A Computable General Equilibrium Analysis of Expanded Use of Alternative Fuel Vehicles

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Abstract: Alternative Fuel Vehicles (AFVs) have been suggested as a low-carbon alternative to conventional fossil fuel-based transportation and have received increasing interest, attention and investment from automakers, consumers, policy makers and researchers. While there have been considerable technologies advances in AFV technology, they require further technological advancement to lower costs sufficiently to capture a significant share of the vehicle market that currently continues to be dominated by conventional fossil fuel technologies. We use a Computable General Equilibrium Model (CGE) – ADAGE to integrate expansion of AFVs along with rapidly changing electricity generation sources to examine the market potential of alternative fuel technologies, interactions between expanded use of these technologies and the U.S. economy, energy and food, coupled with net environmental benefits. Results show that AFVs not only compete with each other, but also with conventional fuel vehicles which promotes biofuel usage. When consumers are sensitive to the electricity price and change their charging behavior, electric cars are expanding more rapidly and use more renewable electricity generation. This brings additional benefit on electricity sector in GHG emissions mitigation. The results would provide some policy implications for policy design on how to view consumers' acceptance of AFVs and their potential role in meeting overall fuel economy standards.

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Alternative Fuel Vehicles (AFVs) have been suggested as a low-carbon alternative to conventional fossil fuel-based transportation and have received increasing interest, attention and investment from automakers, consumers, policy makers and researchers. Among these AFVs are battery electric vehicles (BEV), fuel cell vehicles (FCEV), hybrid (HEV), and compressed natural gas vehicles (GasV). While there have been considerable technologies advances in AFV technology, they require further technological advancement to lower costs sufficiently to capture a significant share of the vehicle market that currently continues to be dominated by conventional fossil fuel technologies. U.S. electricity generation has been shifting rapidly from coal to lower-carbon energy sources, where coal-fired generation declined from 45% in 2010 to about 30% in 2016, while the share for natural gas and renewable sources have risen from 24% to 34%, and from 7% to 9%, respectively, during the same period (U.S.EIA, 2017). In this study, we use a Computable General Equilibrium Model (CGE) to integrate expansion of AFVs along with rapidly changing electricity generation sources to examine the market potential of alternative fuel technologies, interactions between expanded use of these technologies and the U.S. economy, energy and food, coupled with net environmental benefits.

The model used for this analysis is the Applied Dynamic Analysis of the Global Economy (ADAGE) model, a recursive dynamic, multi-region, and multi-sector CGE model. ADAGE follows the classical Arrow-Debreu general equilibrium framework covering all aspects of the economy, including production, consumption, trade, and investment. Households can distinguish between domestic or imported consumption goods, including personal and purchased transportation services. Producer firms maximize profits subject to technology constraints in a nested CES structure. The dynamics in ADAGE are represented by: (i) growth in the available effective labor supply from population growth and changes in labor productivity, (ii) capital accumulation through savings and investment, (iii) changes in stocks of natural resources, and (iv) technological change from improvements in manufacturing, energy efficiency and land productivity. ADAGE is simulated for the period 2010-2050 with a five-year time step.

The key underlying database used in ADAGE is the Global Trade Analysis Project (GTAP) database version 7.1 (Narayanan and Walmsley, Ed., 2008), which was updated from 2004 to the baseline year 2010 using secondary data from World Energy Outlook (WEO, 2010) and International Energy Outlook (IEO 2010) and Food and Agricultural Organization. The model has rich details in energy and electricity generation, agriculture, biofuel, and land. Energy consists of all fossil fuels (refined oil, natural gas, coal and electricity generated from them), nuclear and renewable sources (hydro, wind, solar, geothermal, and biomass). Seven types of first generation biofuels (ethanol from corn, wheat, sugarcane and sugarbeet, and biodiesel from soybean, palm oil and rapeseed) and their byproducts, five types of second generation biofuels (switchgrass, miscanthus, ag residue, forest residue, and pulpwood) are included in the model, used as substitutes of refined oil in on-road transportation. ADAGE has full greenhouse gas (GHG) accounting where baseline data for GHGs (carbon dioxide, CO_2; methane, CH_4; nitrous oxide, N_2O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulphur hexafluoride, SF_6) are from U.S. EPA historical inventory data and projections. ADAGE has been undergoing continuous enhancement since 2009 and has been applied for various economic, energy, and environmental policies analysis, for example, renewable fuel policy analysis (Beach et al., 2011; Cai et al, 2013), climate change evaluation (Cai and Beach, 2013) and food, energy and climate mitigation analysis (Cai, Beach, and Zhang, 2014a, 2014b; Cai and Beach, 2015a, 2015b; Cai and Beach, 2016).

For this study, we used a version where transportation sectors are disaggregated into seven types (light-duty passenger, road freight, road passenger, rail freight, rail passenger, air, water and all other transportation) using data from the Global Change Assessment Model (GCAM), an integrated assessment model developed and maintained by Pacific Northwest National laboratory (PNNL); the U.S. Department of Commerce; and the Bureau of Transportation Statistics within the U.S. Department of Transportation. A nested CES production function is used to represent production in each of these disaggregated transportation sectors with energy, materials, labor and capital as inputs. A unique feature in ADAGE is to build up physical accounts (transportation service defined in terms to vehicle-mile traveled (vmt), price of transportation service ($/vmt), load factor (passenger/vehicle), fuel economy (mile/gallon) and develop linkages between the physical accounts and monetary accounts used in CGE models).

AFVs are introduced as backstop technologies meaning they are not currently available but could enter the market when they become competitive with the conventional technology. First, biofuels are used as substitutes of refined oil in conventional light-duty vehicle (LDV). For AFVs included in the model (electric, fuel cell, hybrid, and compressed natural gas vehicles), input costs, markup factor and fuel economy for LDV are collected from the GCAM database and engineer experts. The markup factor gradually decreases over time, indicating that although these AFVs are not as competitive as conventional LDV using refined oil and biofuels in 2010, they would likely become more competitive over time as the technologies continue to develop. Production technologies for these disaggregated transportation sectors and AFVs are described using nested CES functions. The nesting structures and elasticities of substitution used in ADAGE remain unchanged from the previous version where elasticities of substitution are drawn from EPPA4 (Paltsev, et al, 2005).

In this study, two sets of scenarios are designed to explore the market potential of AFVs in LDV transportation and tradeoffs when facing energy, food, and climate challenges. The first set of scenarios comprises three scenarios where biofuels are set to meet levels specified by the updated Renewable Fuel Standard (RFS2) until 2025 then remain flat from 2025 to 2050: A business-as-usual scenario (BAU) where electricity used to charge AFVs is from grid, a mix of energy sources from fossil fuel, nuclear and renewables; a natural gas scenario (GAS) where electricity used to charge AFVs is from natural gas; and a renewable fuel scenario (REW) where electricity used to charge AFVs is from renewable sources from wind and biomass. These three scenarios are designed to represent different consumers' charging behaviors. In the BAU case, consumers are not sensitive to the electricity price when charging their cars, so they can charge their cars at any time if needed. In the GAS and REW scenarios, consumers are very price-sensitive and only charge their vehicles during off-peak times (such as overnight) where electricity is less expensive and is mainly generated with natural gas or renewables. The time-variant electricity price for household is already implemented in some cities. Compared to the BAU case, the GAS and REW scenarios are very optimistic for AFVs and would promote the usage of electric vehicles. A second set of scenarios would relax the biofuel volume constraint to these three scenarios in the first set, allowing conventional gasoline-biofuels vehicles to compete with AFVs directly. Given the cost advantage in the conventional vehicles relative to AFVs, especially in the earlier periods, we expect to see more biofuels are used in the LDV transportation.

This study enhances our understanding of the prospects of AFVs in response to environmental policy given consumers' preferences. The results from this study help us to explore how AFVs compete with each other, and with conventional fuel vehicles, what is the interaction between transportation and electricity generation, the net impact on emissions from transportation and electricity generation, the two largest emitters in the U.S.A., and overall GHG emissions in U.S.A. It would provide some policy implications for policy design on how to view consumers' acceptance of AFVs and their potential role in meeting overall fuel economy standards.