

ESTIMATING THE GENERAL EQUILIBRIUM BENEFITS OF CHANGES IN AIR QUALITY FROM ADOPTION OF ALTERNATIVE FUEL TECHNOLOGY VEHICLES

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Automobiles are one of the most important means of transportation around the world. The countries with the two largest fleets of personal vehicles are the United States (U.S.) and China. In addition to having large numbers of automobiles, both countries have relatively high miles driven per vehicle. According to the U.S. Department of Transportation Federal Highway Administration (FHWA), in the U.S. the average annual miles driven per driver are 13,476 in 2011⁵. In China, the average distance driven per driver has increased rapidly in recent years, from 10,563 miles per year in 2008 to 15,534 miles in 2010⁶, exceeding the average in the United States. Automobiles offer many benefits for mobility, but there are a number of negative externalities associated with their use, particularly traditional vehicle technologies relying on combustion of fossil fuels. While the use of alternative fuel technologies such as electric vehicles (EV) has been increasing rapidly in the U.S. and China, they still account for a very small share of total vehicle registrations. Researchers have studied the externalities associated with automobile use (Birur et al., 2013; Parry et al., 2007). The most important effect is on human health through exposure to the pollutants emitted into the air from fuel combustion in vehicle engines. The people exposed to toxic air pollutants have an elevated risk of cancer or experiencing other serious health effects, including damage to the immune system, neurological impacts, reduced fertility, developmental delays, and respiratory system impairment (WHO/Europe 2013).

Pollutants from automobile emissions are classified into exhaust emissions from the tailpipe and evaporative emissions from the hood (Mathur et al., 1991). Examples of harmful health pollutants emitted from automobiles are hydrocarbons, nitrogen oxides and nitrous oxide, carbon monoxide, sulfur oxides, particulate matter 2.5 and particulate matter 10⁷, volatile organic compounds, and carbon dioxide⁸. Several studies estimate the cost of air pollution regarding health effects ranges from 837.3 million U.S. dollars in China (Kan et al., 2004) to 194 billion U.S. dollars for a group of Latin American countries (Bell et al., 2006)⁹. In the U.S., air pollution regulations focus mainly on emissions reduction and fuel economy standards. Emission standards are intended to reduce the air pollution by controlling air pollutants per unit of fuel consumption, and fuel economy standards reduce the air pollution by regulating fuel consumption per unit of distance driven.

Policy to mitigate climate change and enhance energy security by expanding alternative fuel vehicles is likely to have co-benefits that are not directly related to greenhouse gas emissions. One of the most important co-benefit effects are those associated with air quality and the resulting impacts on human health. The magnitude of potential co-benefits for human health due to air pollutant emission reduction can make a substantial difference in the net benefits associated with implementation of a GHG mitigation

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⁵ FHWA. <https://www.fhwa.dot.gov/ohim/ohh00/bar8.htm>. Accessed January 12th, 2018.

⁶ See Huo, H., Zhang, Q., He, K., Yao, Z., and Wang, M., 2012.

⁷ See U.S. EPA classification of health effects of particulate Matter. <https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm>

⁸ See http://www.who.int/topics/air_pollution/en/. For the information of pollutants is based on the US EPA air pollutant website. <http://www3.epa.gov/air/airpollutants.html>, and WHO air pollution website

⁹ This includes a large group of countries, Brazil, Chile, Mexico among others

policy. Even though we are focusing on carbon price as our policy for reducing GHG emissions, we will evaluate the environmental and health benefits provided by policies to incentivize the demand for alternative fuel vehicles and reduce emissions for air pollution.

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 computable general equilibrium model developed by RTI International. ADAGE covers all aspects of the economy, including production, consumption, trade, and investment. Households can distinguish between domestic or imported consumption of goods. Producer firms maximize profits with respect to technology constraints in a nested constant elasticity of substitution structure. The model has rich details in energy, transportation, agriculture, biofuel, and land. ADAGE contains greenhouse gases (GHG) accounting (carbon dioxide, CO₂; methane, CH₄; nitrous oxide, N₂O; hydrofluorocarbons, HFCs; perfluorocarbons, PFCs; and sulfur hexafluoride, SF₆). ADAGE is simulated for the period 2010-2050 with a five-year time step.

ADAGE presents a high level of disaggregation of the transportation sector allowing for substitution possibilities among transportation modes. Automobile transportation is disaggregated into light-duty passenger, road freight, road passenger, rail freight, rail passenger, air, water and all other transport means. It is done using disaggregated transportation sector data from the Global Change Assessment Model (GCAM), an integrated assessment model developed by Pacific Northwest National Laboratory (PNNL), as well as data from the U.S. Department of Commerce and the Bureau of Transportation Statistics within the U.S. Department of Transportation. The alternative fuel vehicles included in ADAGE are vehicles using compressed gas, electric battery, hybrids, and hydrogen. ADAGE has the capability to analyze these AFVs technologies and the model assumes they will enter the market when they become competitive with the conventional technology.

For this study, the first task is to introduce air pollutants into ADAGE. The data for global emissions of air pollutants come from the European Commission Joint Research Center - Emissions Database for Global Atmospheric Research¹⁰. The global anthropogenic emission inventory reports time series data for several air pollutants (SO₂, NO_x, CO, NMVOC, NH₃) including detailed information on particulates (PM₁₀, PM_{2.5}, BC, and OC) over the time span 1970-2010. The information about emissions in the global emissions inventory was disaggregated by sector and source. The sectors are agriculture, energy, manufacturing, industrial processing, oil and refineries, construction, on-road and non-road transportation. Air pollutants are modeled in the same way as GHG emissions in ADAGE. They enter the top nest of the CES production functions with an elasticity of substitution between air pollutants and the rest of the inputs used. The model is then able to project future air pollutants under various environmental policies.

A set of carbon price scenarios is used to represent our environmental policies to mitigate climate change and promote the expansion of alternative fuel vehicles. Carbon prices start at \$10, \$20, \$30, \$40 and \$50 per ton of CO₂ in 2015 and then grow by 5% annually through 2050, providing incentives to increase the use of cleaner energy sources in the transportation sector. We expect these scenarios could provide results on how AFVs compete with each other as well as with conventional fuel vehicles and, more importantly, the impact on overall GHG emissions as well as air pollutant emissions under each of these carbon price scenarios.

To quantify the health benefits of the air pollution reductions, we will use the EPA's Environmental Benefits Mapping and Analysis Program (BenMAP) for Global Health Impact Analysis¹¹. The BenMAP open domain software is a useful tool to conduct a "damage function" approach to relate

¹⁰ See http://edgar.jrc.ec.europa.eu/archived_datasets.php. We use EDGARv4.3.1 database.

¹¹ See https://www.epa.gov/sites/production/files/2014-10/documents/benmap_global.pdf

anthropogenic air pollution to health outcomes, such as premature deaths due to exposure to air pollutants. This tool has been used to estimate the burden of disease associated with air pollution in the US and Europe (Ber-man et al., 2012; Davidson et al., 2007), the most recent study is to estimate air pollution effects in Shanghai (Voorhees, et al., 2014). The damage is calculated employing a health impact function (HIF), defined as $\Delta y = (1 - e^{\beta \Delta x}) \cdot y_0 \cdot pop$ where Δy is the change in the number of cases of the health outcome of interest, Δx , is the change in air pollution exposure, β is a risk coefficient of the health outcome of interest drawn from an epidemiological study, y_0 is the baseline incidence rate of the health outcome and pop the size of the exposed population (Voorhees et al., 2014). BenMAP can customize data inputs for different countries, so the input and output data on GDP projection, population and air pollutant emissions from ADAGE in the United States and China from 2010 to 2050 are fed into BenMap to simulate the health benefit from carbon policy.

This results from this study help to quantify the environmental and health co-benefits of air pollutant reduction that may result from a climate policy. The co-benefit is generally not valued in the climate policy analysis, but could provide incentives for cooperation by engaging actors that are averse to the costs of climate policy or unmotivated by avoided climatic damages.

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