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Passenger vehicles that minimize the costs of ownership and environmental damages in the Indian market

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HIGHLIGHTS

- Full costs (private and social) are evaluated for Indian passenger cars.
- Diesel has low ownership costs, but higher climate and health damages.
- Compressed natural gas cars have lower costs and damages than petrol cars.
- Electric cars have higher damages due to electricity generation emissions.
- CNG and less carbon intensive electricity minimizes Indian cars' full cost.

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ABSTRACT

Rapid expansion of population and income growth in developing countries, such as India, is increasing the demand for many goods and services, including four-wheeled passenger cars. Passenger cars provide personal mobility; however, they also have negative implications for human wellbeing from increased air pollutants and greenhouse gases (GHG). Here, we evaluate the range of passenger vehicles available in the Indian market to identify options that minimize costs, human health effects and climate damages. Our approach is to compare alternative fuel/powertrain vehicles with similar conventional gasoline fueled vehicles and assess the differences in full (private and societal) costs for each pair. Private costs are the combination of capital costs and the discounted expected future fuel costs over the vehicle lifetime. The costs to human health from air quality are calculated using intake fractions to estimate exposure and literature values for the damage costs adjusted by benefits transfer methods. We use the Social Cost of Carbon to estimate climate damages. We find that, on average, the net present value (NPV) of the full costs of compressed natural gas (CNG) vehicles are lower than comparable gasoline vehicles, while, diesel vehicles have higher costs. Presently, electric vehicles have higher private costs (due to high capital costs) and societal costs (due to electricity generation emissions). Either a less carbon intensive electricity grid or an increase in the CNG fleet would minimize total costs, human health effects and GHG emissions from the passenger vehicle fleet. Policy makers should consider promoting the use of CNG vehicles, although this would require supporting infrastructure improvements.

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1. Introduction

The ubiquity of four-door passenger vehicles in developed countries speaks to the substantial benefits provided to their owners and their passengers, such as comfort and convenience. These vehicles have also introduced major societal-level risks, namely premature mortality from exposure to adverse air quality and the widespread impacts of climate change from greenhouse gas (GHG) emissions. Higher fuel economy, more stringent tailpipe emission standards and improved fuel quality have reduced these impacts on a per-vehicle basis, but overall emissions continue to rise due to an increase in demand [1]. Currently, much of the growth in ownership of passenger vehicles is found in developing countries [2]. While these vehicles substantially improve individual mobility, the continued addition of new vehicles will further exacerbate the poor air quality that is found in many urban centers in developing countries [3] and present a challenge for climate mitigation efforts [4].

One way to reduce societal impacts from passenger vehicles is to promote alternative fuel/powertrain vehicles, such as hybrid and electric vehicles. However, these vehicles generally have a

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higher cost of ownership than the conventional gasoline or diesel options. Systematic benefit-cost analysis (BCA) of passenger vehicle options can provide guidance to policymakers who aim to balance these private benefits and societal costs [5]. Here, we employ a benefit-cost analysis (BCA) framework to evaluate the costs of ownership and the environmental and human health effects of alternative fuel/powertrain compared to gasoline (petrol) four-door passenger vehicles for developing countries, using India as a case study. Specifically, we identify vehicles that minimize both the private costs and environmental burden by comparing the total costs of each vehicle, comprised of the private costs of vehicle ownership and the social costs of the environmental attributes. Existing benefit-cost and other analyses of the societal costs of vehicle emissions have been conducted primarily for fuel/powertrain options in the United States (US) and Europe [6] which may not translate to developing countries. First, the vehicle markets in developing countries often have a wider range of vehicles targeting a more diverse consumer market. Second, some methods that are employed for analysis in developed countries may be inappropriate or less amenable to developing countries due to different conditions or data availability. Additionally, there is a pressing need for policy guidance for developing countries. Since vehicles and infrastructure are durable goods, decisions made during this period of growth will define the environmental attributes of the vehicle fleet for decades.

In a recent review, Roosen et al. [6] identified 12 studies that evaluated the private and societal costs of vehicles, monetizing GHG and/or air pollutants from tailpipe emissions or electricity production for electric vehicles. Overall, these studies show that while conventional gasoline fueled vehicles have the lowest private costs of ownership, alternative fuel/powertrain vehicles can dominate on their full costs due to the reductions in the societal costs from the GHG and other air pollutants. The studies, however, draw a wide range of conclusions depending on assumptions about capital costs, fuel prices and the effectiveness of emission controls. For example, Keefe et al. [7] conclude that diesel passenger vehicles are preferred on their full costs when compared to gasoline and gasoline hybrid electric vehicles (HEV), assuming that the diesel vehicles attained the stated US Environmental Protection Agency (USEPA) tailpipe emission standards [7]. By contrast, Lipman and Delucchi [8] find that hybrid vehicles outperform the diesel and gasoline fueled vehicles by making more favorable assumptions about hybrids' capital costs and fuel economy [8]. Expanding the alternatives to include the wider range of vehicles that are available in the European market, Torchio and Santarelli [9] found that the natural gas fueled vehicles had the lowest full costs [9]. There has also been a growing interest in the potential benefits of plug-in electric (PHEV) and all electric vehicles (EV). Previous analysis has suggested that the monetized damages of the health impacts and the GHG emissions are smaller than the difference in capital costs between PHEVs and conventional gasoline vehicles [10]. These benefits, however, are also highly dependent on the electricity generation source for both air quality and GHG emissions. For example, Tessum et al. [11] found that charging EVs with coal-based or the US grid average would increase monetized health impacts from air pollution by 80% or more relative to using conventional gasoline, although natural gas and other renewables would reduce health impacts by 50% or more [11]. Further, Tamayao et al. [12] concluded that the GHG emissions from PHEVs could exceed those of HEVs depending on the location in the US [12].

Given the range of factors that may influence vehicle selection, these analyses may not provide sufficient guidance for policymakers in developing countries. We select India as an important case study of a rapidly developing country. Sales of four-wheel passenger vehicles more than doubled from approximately 1.14 million in 2005–2006 to 2.6 million in 2014–15 [13]. Thus, an evaluation of the benefits and costs of these vehicles is timely for policymakers seeking to achieve air quality and GHG goals. The Indian case study also provides both opportunities and challenges in terms of approaches for this type of analysis. Unlike the more mature US market that is dominated by a few vehicle types, the Indian car market supports a wide range of vehicles: gasoline spark injection, liquefied petroleum gas (LPG, also known as AutoGas) spark injection, compressed natural gas (CNG) spark injection, compression injection diesel, and electric vehicles (EV). As a result, we can use actual data on the retail prices observed by Indian consumers. Comparing vehicles based on their actual prices for different size classifications, rather than more generic techno-economic estimates, is important since individuals make their purchase decisions based on the vehicle prices that they observe in the market as well as observed fuel prices. Due to the limited availability of data, many assessments of alternative vehicles are based on techno-economic estimates (e.g. [7]). While these modeling approaches are often employed, especially for less mature technologies like PHEVs (e.g. [14]), it is generally preferable to use actual retail prices as they reflect the prices faced by the consumers (e.g. [15]).

We also investigate the influence of current policies promulgated by the national government on the present and future costs and environmental attributes of the vehicle fleet, using benefit valuations that are appropriate for an Indian context. Indian tailpipe emission standards have generally followed the policies developed by the European Union [16]. Currently, new vehicles sold in urban areas (13 major cities) must achieve Bharat IV standards (EURO 4) with the rest of the country meeting Bharat III (EURO 3) standards. It is expected that the Bharat IV will apply nationwide by 2017 [17]. Similar to other large urban centers in developing countries, there are high levels of fine particulate matter ($PM_{2.5}$) and other air pollutants in India [18]. To address persistent air quality problems, Bharat VI (EURO 6) standards are to come into effect in 2020. Further, the government has outlined a number of policies in its Intended Nationally Determined Contribution (INDC) as part of lead up to the Paris Climate Agreement. Notably, the Government of India included its National Electric Mobility Mission Plan (NEMMP) [19]. This plan envisions 5–7 million hybrids, PHEVs and all electric vehicles in the Indian market by 2020.

2. Data and methods

We compare the private and societal costs of owning and operating alternative fuel/powertrain vehicles to conventional gasoline vehicles. The vehicle with the lowest full cost is the preferred option. In this analysis, we focus on the usage phase of the vehicle, treating consumer behavior related to driving patterns and vehicle lifetime as well as fuel prices, infrastructure and the electricity generation sector parametrically through a sensitivity analysis. Our approach is to pair vehicles of the same manufacturer, model and variant that differ only in their fuel/powertrain. This allows us to account for as many features (e.g. trim, air conditioning, etc...) as possible that could potentially explain the difference in the observed market prices for the vehicles.

In this section, we first describe the method for private and social cost calculations. Second, we describe the collection of a comprehensive dataset of four door passenger vehicles available in India, and our approach to the pairing of vehicles. Third, we present our estimates for the private costs of purchasing and operating the vehicles. Finally, we describe the social cost calculations, including tailpipe emissions and our approach for estimating the value of the emissions. The costs and emissions for other sectors are beyond the scope of this analysis, such as expanding the fueling

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