Transportation and the Environment
A Review of Empirical Literature

Shanjun Li
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Abstract

In urban areas around the world, increasing motorization and growing travel demand make the urban transportation sector an ever-greater contributor to local air pollution and greenhouse gas emissions. The situation is particularly acute in developing countries, where growing metropolitan regions suffer some of the world’s highest levels of air pollution. Policies that seek to develop and manage this transportation sector—to meet rising demand linked to economic growth and safeguard the environment and human health—have had strikingly different results, with some inadvertently exacerbating the traffic and pollution they seek to mitigate. This paper provides an overview of the findings of the recent literature on the impacts of a host of urban transportation policies used in developed and developing country settings. The paper identifies research challenges and future areas of study of transportation policies, which can have important, long-lasting impacts on urban life and global climate change.

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Transportation and the Environment: A Review of Empirical Literature

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1. Introduction

Air pollution and climate change represent serious threats to human health. In 2016, air pollution was responsible for about 7 million deaths from various life-shortening diseases, including heart disease, lung cancer, and stroke, according to the World Health Organization (WHO). The public health and economics literatures have established that air pollution increases mortality, especially among the most vulnerable groups, including infants and older adults, and that it leads to large morbidity costs. In addition to local air pollution, climate change resulting from emissions of greenhouse gases is expected to cause far-reaching and sweeping economic and societal changes that are likely to affect agriculture, biodiversity, economic growth, geopolitics, human health, and world peace.

Many developing countries, especially rapidly growing countries, are experiencing pressing environmental challenges as a result of the dramatic increase in fossil fuel consumption to meet the need for consumption and production, limited access to clean technologies, and the lack of stringent and well-enforced environmental regulations. The populations in these countries are particularly vulnerable to adverse environmental conditions because of the lack of effective government interventions, and the costs of and limits on options available to individuals to prevent or mitigate the effects of pollution.

Road vehicles are important sources of fine particulate matter (PM$_{2.5}$), nitrogen oxides, carbon dioxide (CO$_2$) and other pollution. Panel (a) of Figure 1 depicts the level of PM$_{2.5}$ across the globe. It shows that concentrations tend to be higher in low- and middle-income countries. The United States and Japan were historically the world’s major sources of CO$_2$ emissions. Panel (b) shows that over the past two decades, emissions from developing countries such as China and India surged to catch up. In 2006, China surpassed the United States to become the world’s largest emitter of CO$_2$.

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2 WHO Global Ambient Air Quality Database: https://www.who.int/airpollution/data/cities/en/.
3 Studies on the mortality impact of air pollution include Chay & Greenstone (2003), Currie & Neidell (2005), Currie & Walker (2011), Knittel et al. (2016), and Deryugina et al. (2019). Studies on morbidity costs include Moretti & Neidell (2011), Deschênes et al. (2017), Barwick et al. (2019), and Williams & Phaneuf (2019).
4 Recent papers on the impacts of climate change include Nordhaus (2006) and Dell et al. (2012) on economic growth; Mendelsohn et al. (1994), Schlenker et al. (2005), Deschênes & Greenstone (2007), and Burke & Emerick (2016) on agriculture; Deschênes & Moretti (2009), Deschênes & Greenstone (2011), and Barreca et al. (2016) on mortality; and Miguel et al. (2004), Hsiang et al. (2011), and Jia (2014) on social conflict.
Figure 1: Fine Particles (PM$_{2.5}$) and GHG Emissions by Country

Panel (a) PM$_{2.5}$ concentration in 2017

Panel (b) Average GHG emission between 2005 and 2016

Notes: Figure 1 shows the spatial distribution of PM$_{2.5}$ concentrations in 2017 and the average greenhouse gas (GHG) emissions between 2005 and 2016. Reconstructed based on data.
Rapid urbanization in developing countries presents both challenges and opportunities in addressing the environmental challenges (Kahn 2006). The world’s urban population increased from less than 1.4 billion (or 36%) in 1960 to nearly 4.2 billion (or 55%) in 2018. By 2050, over two-thirds of the world’s population are projected to live in urban areas and the rural to urban migration during this process will mostly occur in developing countries. On the one hand, the high concentration of people and activities in cities could lead to severe traffic congestion and exacerbate air pollution, especially with the rise in vehicle ownership in emerging economies. On the other hand, cities have the potential to organize economic activities spatially to reduce energy consumption and environmental impacts and to better take advantage of the economies of scale in public transit. Understanding the role of transportation in addressing urban environmental challenges has important implications for policy design to foster the emergence of green cities.

The transportation sector, which relies heavily on fossil fuels, is a major source of air pollution and greenhouse gas (GHG) emissions. The WHO estimates that road transport contributes 30 percent of particulate emissions in European cities and up to 50 percent in countries in the Organisation for Economic Co-operation and Development (OECD). According to the US Environmental Protection Agency (EPA), the transportation sector is responsible for about 10 percent of particulate, more than 55 percent of nitrogen oxide (NOx), and about 10 percent of volatile organic compound (VOC) emissions in the United States.

Because of the rapid rise in private vehicle ownership and travel demand, as well as the relatively low fuel efficiency in developing countries, the transportation sector plays an increasingly significant role in local air quality. Figure 2 shows the increase in new passenger vehicle registrations in selected countries from 2005 to 2017. Among developed countries, new vehicle sales were stable or declined slightly during this period. By contrast, China and India experienced dramatic increases in vehicle ownership, with total new passenger vehicles increasing fivefold in China and 2.5 times in India. Although per capita vehicle ownership is still

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relatively low in developing countries, and total gasoline consumption is still far behind that in the United States (Figure 3), the upward trend in these countries is substantial.

**Figure 2: New Passenger Car Registrations for Selected Countries**

![Graph showing new passenger car registrations for selected countries from 2005 to 2019.](image)

*Notes: Figure 2 shows the new passenger car registrations and changes from 2005 to 2017 using data from the International Organization of Motor Vehicle Manufacturers (www.oica.net). Axis on the right corresponds to China’s new passenger car registrations.*

**Figure 3: Fuel Consumption by Country**

**Panel (a) Gasoline Consumption by Country**
Panel (b) Distillate Fuel Oil Consumption by Country
Notes: Figure 3 shows the global distribution of gasoline and distillate fuel consumption between 2015 and 2016. Data source: U.S. Energy Information Administration.
In addition to private vehicles, there has been a sharp increase of two- and three-wheelers in developing countries driven by the increased demand for low-cost motorized transport. In Asia more than two-thirds of the total vehicle population consists of two- and three-wheelers in many countries (Hook and Nadal 2011). While two- and three-wheelers such as motorcycles are more efficient than automobile engines, and so generally emit less greenhouse gases, motorcycles emit far more smog-forming hydrocarbons and nitrogen oxides, as well as carbon monoxide on a per passenger-kilometer basis. Since two- and three-wheelers have been increasingly replacing non-motorized options, such as cycling and walking, their increased uptake also contributes to increasing transport-induced air pollution in developing countries.

As household income rises in developing countries, the need for travel and the desire for automobile ownership grow, and ability to pay for a cleaner environment increases as well. In order to strike a balance between these competing incentives, policy makers need to recognize that (a) automobile usage generates several types of externalities (including pollution, congestion, noise, accidents, and road damage) that need to be addressed by policy interventions (Parry et al. 2007), and (b) automobiles and transportation infrastructure are durable goods, such that short-term decisions on vehicle purchase and transportation network design can have far-reaching implications for the emissions trajectory for decades to come. Government policies need to be forward-looking and take long-run household behavioral responses into account.

The motorization path of developed countries does not provide clear guidance or a model for the developing world. Sprawling residential-only developments that dominate most suburban areas in North America limit the ability of people to walk or cycle for their daily travel requirements. Such urban development model produced a reliance on private motorized transport. With rapid urbanization, policy makers in developing countries have a unique opportunity to integrate land-use planning and transport to encourage low-emission low-motorized mobility. Policies that actively pursue land-use elements, particularly a focus towards compact, connected and efficient forms of urban development, can encourage a modal shift from private motor vehicles to walking, cycling and public transport (Ardila-Gomez 2019). These policies include building dense, mixed-used communities with well-connected street networks, investing in safe walking and cycling infrastructure, such as designated bike facilities and lighting amenities, increasing parking spots for bicycle parking while limiting parking for private
vehicles, ensuring physical connection for seamless inter-modal trips between cycling and mass transit systems such as BRTs and adopting innovative financing mechanisms to support sustainable urban transport (Ardila-Gomez and Ortwgon-Sanchez, 2016; Sibilski and Targa 2019).

Giving priority to non-automotive modes of transportation and making cycling and walking viable options is a first-best solution to solve transportation challenges. In situations where land use planning is less flexible, a suite of alternative policy tools has been used to reduce urban air pollution from automobiles. These tools include demand- and supply-side policies that aim to encourage travel mode shifts, reduce emission intensity levels of specific modes via fuel-economy and emission standards, and promote alternative fuels or zero-emission technologies (Figure 1). Such policies can either be designed based on a command-and-control approach or alternatively on market-based instruments.

This study reviews recent research on various policy tools aimed at addressing transportation-induced air pollution issues. We focus primarily on recent empirical papers published in peer reviewed journals that study the causal impact of policies. The largest share of papers looks at non-land use related policies and this review reflects this bias, i.e., most papers reviewed in this paper investigate the effectiveness of policies aimed at reducing emissions from motorized travel mode. The main metric to be used in evaluating the relative performance of different policies will be their effectiveness in addressing the pollution challenge; always giving due consideration to the empirical challenges involved in identifying the causal impacts of such policies on pollution.6 Furthermore, some of the environmental policies also bring collateral benefits in addressing other types of externalities associated with road transportation, such as congestion and accidents. They will also be discussed when relevant.

The remainder of the paper is organized as follows. Sections 2-4 discuss various transportation policies and their effectiveness in reducing emissions, including those aimed at encouraging modal shifts, promoting the adoption of alternative fuel vehicles, and reducing

6 Because the choice of travel modes is also tied to housing and job location choices, smart urban planning can play an important role in curbing car-related emissions by reducing travel distances or eliminating the need to travel altogether. This paper does not examine the cost effectiveness of urban policies. Section 5 briefly discusses actions that can help improve system-wide efficiency, such as ridesharing and autonomous driving.
tailpipe emissions. Section 5 concludes and discusses future research areas. The main methodological features and empirical results from the substantial literature surveyed are summarized in a reference table in the appendix.

Table 1 Transportation policies aimed at addressing air pollution issues

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2 Policies to Promote Modal Shifts

To ease traffic congestion and pollution, governments have adopted various policies to stimulate a shift from car to public and other less emission-intensive modes of transport. In this section, we review the effectiveness of these policies including expansion of public transit, license-based driving restrictions, auction or lottery-based purchase restrictions, and congestion pricing.

2.1 Expansion of Public Transit

Local governments often use the expansion of road and public transit networks as a way to tackle air pollution and traffic congestion. Although, in many cases, investment in mass transit is primarily driven by concerns about congestion, with tackling air pollution more of a secondary benefit. In Beijing, the government invested more than $67 billion in transportation infrastructure between 2007 and 2015, greatly expanding the public transit network by adding 14 new subway...
lines and more than 200 bus routes (3,300 new buses). Similar expansions are happening in India, Mexico, and many other emerging economies. Although it requires massive funding, this type of investment can also stimulate economic activities and facilitate trade (Redding & Turner 2015).

With the goal of reducing traffic-related air pollution and traffic congestion, supply-side policies such as expanding the public transit network can create two countervailing forces on air quality. Improving the public transit network can divert commuters from driving private vehicles to public transport (Mohring 1972). This traffic diversion effect (the “Mohring effect”) could potentially reduce traffic congestion and vehicle emissions. However, improving transportation infrastructure (by increasing road capacity or expanding public transit) can reduce the cost of travel by reducing congestion and increasing accessibility, and generate more economic activity, resulting in an increase in travel demand and driving (Vickrey 1969). The net effects of increase in public transit supply may depend on the time horizon. In the short run, the diversion effect could play a more important role as there is spare capacity in the transportation system. In the medium to long run, induced demand may offset the diversion effect, causing congestion and more pollution. For example, Duranton & Turner (2011) find that traffic volume increased as a result of the expansion of highway capacity in US cities between 1983 and 2003. Although the expansion of road capacity can initially reduce traffic congestion and air pollution, it increases travel demand in the long run, eroding the initial improvement in traffic conditions.

Given the high cost of transportation infrastructure and potential countervailing forces at play, empirically estimating the impact of supply-side policies on air quality is important. The central challenge lies in finding exogenous variation in public transit infrastructure, which could be confounded with other unobserved factors. For example, urban planners may situate public transit (such as the subway) in areas where population and economic activities are projected to grow. In this case, air quality in those areas may have deteriorated in the counterfactual scenario of no expansion of public transit. The issue of endogenous location could bias the true impact of the subway expansion in the empirical analysis.

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To tackle the identification challenge, researchers have used the regression discontinuity (RD)-in-time, difference-in-differences (DID), and event study (ES) approaches, which rely on different identification assumptions. The key assumption behind the RD in time and ES approaches is that no unobservables exhibit discrete changes at the time of treatment (e.g., subway opening), so as not to confound the impact of the treatment. The key identification assumption behind DID is the parallel trend assumption, i.e., unobservables do not affect the treatment and control groups differently in the absence of the treatment.

Chen & Whalley (2012) estimate the effects of the opening of one subway line in Taipei on air pollution based on the RD in time framework. They find that the opening of the subway line reduced carbon monoxide (CO) emissions by 5–15 percent. Employing an approach similar to that used by Chen & Whalley (2012), Goel & Gupta (2017) use the RD method to examine the impact of the Delhi Metro expansion on air quality. They find a 34 percent localized reduction in CO in the short run. Using an ES design, Gendron-Carrier et al. (2018) examine 43 cities across the world that opened new subway systems between 2000 and 2014. They find that particulate concentrations dropped by 4 percent on average following the opening of a new subway system. Zheng et al. (2019) use the DID method to estimate the impacts of the opening of the first subway line in Changsha, China. They find an 18 percent reduction in CO in areas close to subway stations.

A strategy to deal with the endogenous location concern of the public transit is the instrumental variable (IV) method. The instrument should provide variation that affects location choices but is exogenous to contemporaneous shocks to air pollution and other outcome variables. Baum-Snow (2007) uses planned routes (many of which were not built) as the IV for US highways to examine the trend of suburbanization; Faber (2014) constructs a hypothetical highway system in China based on historical planning maps using a minimum spanning tree (MST) approach and topographic variation to examine trade integration and industrialization. Li et al. (2019) follow a similar strategy to examine the impact of Beijing’s subway system, using the original planning routes as the IV.

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9 The RD-in-time method uses time as the running variable and assumes that the impact of unobservables on air quality can be captured by flexible functions of the time trend. The identification relies mainly on time-series variation, different from the traditional RD in cross-sectional settings. The RD in time, in essence, is the same as the event study method which explicitly uses pre- and post-event data for identification. Hausman and Rapson (2018) discuss the pitfalls and recommendations for addressing them when applying the RD-in-time method.
An additional empirical challenge in this literature is accounting for the spillover effect of the transportation network. Local changes in road or subway networks could have a system-wide impact, making it difficult to find a valid control group in the DID framework. Li et al. (2019) employ a continuous measure of subway network density as the key regressor to estimate the citywide effect. The network density varies across space within a city and over time for a given location as a result of the expansion of the subway network. A new subway line would more sharply increase network density in adjacent areas than in areas that are farther away. Using the predetermined planning map as an IV, the authors estimate the effect of subway expansion on air pollution for the rapid build-out of 14 subway lines in Beijing from 2008 to 2016. They contrast the estimates based on this approach with those from a distance-based DID approach. The DID approach focuses on the local effect and provides a larger estimate; the network density approach allows for the spillover effect across the whole network, and relies on the assumption that the impact diminishes over distance.

Several other studies examine the impact of expanding bus and railway services on air quality or traffic congestion. Anas & Timilsina (2015) use a simple core-periphery model of Beijing to numerically assess the lock-in effects of transportation infrastructure in Beijing. They find that increasing bus services in the city center would reduce overall CO\textsubscript{2} emissions, and that expanding suburban roads would increase them. Lalive et al. (2013) and Bel & Holst (2018) show that increasing rail services in Germany, and expanding bus rapid transit (BRT) services in Mexico City reduced emissions of pollutants such as CO, NO\textsubscript{x}, and PM\textsubscript{2.5}. Three studies – by Silva et al. (2012) in Brazil, Anderson (2014) in Los Angeles, and Bauernschuster et al. (2017) in Germany – take advantage of exogenous variations in public transit supply created by strikes of public transit workers to show that decreased public transit use led to more air pollution and traffic congestion.

Although improving transportation infrastructure is necessary to address traffic congestion and promote economic activities, empirical evidence is mixed regarding whether it is an effective way to improve environmental quality. Findings from the literature presented above suggest that expanding subways has reduced air pollution at least in the short run, However, Beaudoin & Lin-Lawell (2017) and Rivers et al. (in press) find no evidence of air quality improvement from the expansion of public transit. In fact, Beaudoin & Lin-Lawell (2017) find that the increase in US public transit supply between 1991 and 2011 led to a small deterioration...
in overall air quality, especially for NO\textsubscript{2} and PM\textsubscript{10}. Li et al. (2019) estimate that the benefit from pollution reduction generated by the rapid subway expansion in Beijing represents only a small fraction of the overall construction and operating costs. In contrast, the benefit from congestion relief is much larger and of the same order of magnitude as the costs.

It is important to recognize that urban areas vary significantly across socioeconomic and geographic characteristics that may influence the effect of public transit supply. The benefits of public transit are likely to be significantly higher in regions with high population density, extensive public transit networks/low motorization rates, and large low-income population who cannot afford private vehicles. Heterogeneity across urban areas may explain the different findings in the literature. Further, existing results in the literature should be interpreted in the context of inadequate road pricing. The ability of public transit to reduce air pollution and congestion could be greatly improved if individuals are required to pay the full marginal social cost of auto travel (Ardila-Gomez 2019). Finally, in developing countries that are experiencing rapid urbanization, investment on public transit today is necessary to influence land-use patterns in order to build more efficient mass transit system in the future and to avoid locking into an unsustainable and costly infrastructure (Block et al. 2013). For above reasons, findings on the public transit cost-benefit analysis have to be interpreted in the specific urban context and there may be limited scope for the external validity of existing analysis.

\section*{2.2 Restrictions on Driving and Vehicle Purchase}

Governments can use a variety of demand-side policies to incentivize commuters to change their travel behavior (switching from driving to public transit, for example, or driving less during congested hours). This subsection discusses command-and-control approaches. (Subsection 2.3 discusses market-based policies.)

The command-and-control approach has been widely adopted, especially in developing countries. This approach includes driving and vehicle-purchasing restrictions. The driving restriction (or road space rationing) policy was first introduced in Athens, Greece, in 1982; Santiago, Chile, was the second city to adopt it, in 1986. In 1989, Mexico City started perhaps the longest-running and best-known license-based driving restriction policy. Based on the last digit of the vehicle’s license plate, the policy restricts about 20 percent of vehicles from driving on each workday. In 2008, Beijing’s municipal government adopted the driving restriction policy
to prepare for the 2008 Olympic Games. Initially, the government adopted an even-day/odd-day policy, whereby a vehicle could be driven only on an odd or even day, based on its license plate. After the Olympics, the restriction was relaxed so that the license number-based ban applied on only one designated weekday – a policy also used in Mexico City. In recent years, Paris, Rome, Milan, Oslo, and New Delhi imposed temporary driving restrictions to address congestion and air pollution. Many German cities implemented low emission zone policies, which ban high-polluting vehicles from driving in certain areas (Wolff 2014).

Several studies examine the impact of these policies on traffic congestion and the environment. Like the literature on supply-side policies, these studies commonly adopt quasi-experimental strategies, such as the RD-in-time, DID, and ES methods, using identification from both spatial and temporal variations. The empirical findings are mixed, highlighting the importance of understanding competing forces and consumer responses in policy design.

Using the RD method, Davis (2008) finds that the driving restriction led to worse air quality in Mexico City because the policy incentivized drivers to circumvent the restriction by purchasing a second vehicle, which tended to be older and dirtier. In contrast, the evidence on the environmental impact of Beijing’s driving restriction policy has been largely positive. Using both RD and DID methods, Viard & Fu (2015) show that the every-other-day driving restrictions in Beijing led to a 19 percent reduction in air pollution and that the one-day-a-week restrictions led to a 7 percent reduction. Zhong et al. (2017) confirm that the driving restriction policy in Beijing reduced both traffic congestion and air pollution, and, as a result, emergency room visits also declined due to improved public health.

The difference in the environmental outcomes of the license-based driving restriction between Mexico City and Beijing suggests that an effective policy design needs to pay attention to the broad operating environment, which affects consumer responses to the policy and, ultimately, the effectiveness of the policy. In response to the driving restriction policy, commuters in Beijing have mainly resorted to public transit instead of the purchase of the second vehicle.

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10 See Wolff & Perry (2010) for a review of low emission zone policies in European cities.
11 Because of NAFTA, Mexico has become a net importer of used cars from the United States. Used cars are very cheap in Mexico.
12 These results are consistent with the findings of Chen et al. (2013), who examine short-term environmental measures, including the driving restriction policy and other policies the Chinese government adopted in preparing for the 2008 Olympic Games. They find a positive but temporary impact of the measures on air quality.
vehicle to meet their travel demand (Xu et al. 2015). There are two important institutional differences between Mexico City and Beijing. First, as previously discussed, Beijing has been investing heavily in improving the public transit system since 2007. The expansion of public transit, including subway and buses, provides residents alternative travel modes. Second, the Beijing municipal government adopted two policies that limited households’ ability to purchase a second vehicle. At the time of the driving restriction policy, the Beijing government also implemented a policy to restrict sales and registrations of used vehicles from other cities that did not meet Beijing’s tailpipe emission standards. In addition, Beijing implemented a quota system on vehicle purchases from 2011 that limited households’ ability to purchase a second (new or used) vehicle. The theoretical model developed by Zhang et al. (2017) highlights the uncertainty of the effects on air quality that result from license platted-based driving restrictions. They show both theoretically and empirically that the same policy could lead to different outcomes depending on the substitution among travel modes, the purchase of second vehicles, and atmospheric chemistry, which could result in differential impacts across pollutants. Other studies analyze the distributional and welfare impact of driving restriction policies. For example, Haddad et al. (2019) find potential trade-offs between efficiency and equity in the case of policies that restrict cars’ access to the city.

Another command-and-control policy to curb the growth in travel demand is a vehicle quota system. In 1990 Singapore adopted such a policy, allocating licenses (known as certificates of entitlement [COEs]) through a monthly auction system. The cap is defined over different categories of vehicles based on engine power. The COE price ran as high as SGD 50,000 (about USD 35,000) for large passenger vehicles. In 1994 Shanghai started an auction system to allocate limited vehicle licenses; it switched to an online system with a reservation price in 2008. The monthly cap has been about 10,000 units. The number of bidders per month is about 150,000 to 200,000; the average winning bid was about CNY 90,000 (about USD 14,000) in recent years.

In 2011, the Beijing municipal government implemented a vehicle quota policy to reduce air pollution and traffic congestion. It uses a lottery system to allocate limited vehicle licenses. The lottery was initially held monthly; since 2014, it has been held every second month. The quota was reduced over time, and the odds of winning decreased substantially.13 Five other

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13 The odds of winning the license plate lottery in Beijing decreased from 1:10 in early 2011 to nearly 1:2,000 in 2018 because the cap tightened, and the pool of lottery participants increased dramatically.
cities in China now have vehicle quota systems based on various allocation mechanisms: Guiyang and Guangzhou adopted license lotteries in July 2011 and August 2012, respectively; Tianjin, Hangzhou, and Shenzhen started to implement a hybrid system in January, March, and December 2014, respectively.

Li (2018) uses a structural econometric model to compare the allocative efficiency and environmental outcomes of auction and lottery systems. The analysis suggests that the lottery system leads to a large welfare loss from misallocation, although it has an advantage over an auction in terms of reducing externalities such as air pollution from automobile usage. The environmental impacts of the purchase restriction policy warrant future research. The short-run impact is likely small; hence, given that the first-order effect of the policy is on the flow rather than the vehicle stock, the short-term impact is hard to empirically detect. The long-run impact could be more significant, but it is harder to identify because there is more room for confounding factors to be at play in a longer time horizon.

A special case of the vehicle purchase restriction is restrictions on second-hand vehicle trade. Most countries have some form of barrier on second-hand vehicle imports for various reasons. In many developing countries, the least expensive new vehicles are often locally produced. Restrictions imposed on used car import protects domestic production and sales of new vehicles. However, 58 of 101 countries around the world without domestic vehicle production limit the import of used cars (Coffin et al, 2016). Environmental protection and safety are primary concerns behind the restrictions on used vehicle imports in these countries. The level of used car import restrictions varies by country. Some countries outrightly ban used vehicles import such as Argentina, Brazil, Chile, Uruguay, Sudan, Morocco and Philippines. Other countries like Algeria, Jamaica, Ghana, Kuwait, Mexico, Niger, Tanzania and Senegal have adapted various import age restrictions for used vehicles. For example, Niger has an age restriction of five years (UN, 2019).

In some countries, age limits have been replaced by emission standards and taxations regimes that favor cleaner, newer vehicles. Instead of imposing age restriction, Costa Rica has instituted a “selective taxation” scheme to deal with second-hand imported vehicles. Tax rate increases with the age. For example, the selective tax rate is 30% for imports with age less than or

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14 Chin & Smith (1997), Koh (2003), Chen & Zhao (2013), and Xiao et al. (2017) have examined the impact of the quota policy on vehicle purchases and consumer welfare in Singapore and China.
equal to 3 whereas 53% for imports with older than 6 years in 2012. In addition, loans to buy new
cars have a term up to seven years whereas loans to buy second-hand cars are only granted up to
three years. As a result, import of used vehicles declined from 49% to 30% between 2005 and
2015 in Costa Rica. However, since the price on international markets is so low, many vehicles
older than 10 years are still imported.

Ukraine, the fastest growing market for electric vehicles in Europe, incentivizes the
purchase of clean vehicles by levying lower taxes on cars with smaller engine capacity and lower
CO₂ emissions. In addition, Ukraine abolished VAT and excise taxes for electric vehicles import
as of 2018 (UN, 2019). Countries like Panama and Mexico also require Euro 1 and Euro 4 light
duty vehicle emission standards respectively (in addition to age restrictions).

Trade restrictions affect the composition of the vehicle stock. The environmental
implications of trade restrictions depends on how the environmental characteristics of traded
vehicles compare to the existing stock. Kahn and Davis (2008) find that since trade restrictions
were eliminated in 2005, Mexico has imported over 2.5 million used vehicles from the United
States. Traded vehicles are dirtier than the stock of vehicles in the United States and cleaner than
the stock in Mexico, so when a vehicle is traded from the United States to Mexico average
vehicle emissions per mile tend to decrease in both countries. Overall, however, trade has
increased total lifetime emissions, primarily because of low vehicle retirement rates in Mexico.

2.3 Congestion Pricing
The command-and-control approaches that restrict driving or vehicle ownership are not the first-
best policies to address environmental and congestion externalities; such policies can lead to
unintended consequences (Davis 2008). Market-based policies have gained more traction from
policy makers in recent years. This subsection discusses congestion pricing as a market-based
policy tool to affect travel behaviors such as travel time, distance, frequency, and modes.

Congestion pricing was first proposed by Vickrey (1959), who recognized congestion as
a classic externality and identified the mispricing of transport resources as its root cause. In
principle, congestion prices should reflect the marginal social cost of each trip in terms of the
impacts on others including the cost of air pollution and traffic congestion. To this end,
congestion pricing should be designed to allow charges to vary by location and time based on the
spatial and temporal variation of the congestion externality. To address distributional concerns
and further promote the use of public transit, the revenue raised can be used to improve access to and the quality of public transit.

Singapore adopted the first congestion pricing scheme in 1975. Some European cities have adopted area-based congestion pricing (London in 2003, Stockholm in 2006, Milan in 2008, Gothenburg in 2013). In the United States, several area-based schemes were proposed but failed to be implemented over the years. New York state’s 2019 budget proposes congestion pricing on vehicles that enter Manhattan below 60th Street. If adopted, New York City would become the first US city to use congestion pricing.15 Real-time congestion pricing is now technically feasible. Singapore is slated to become the first city to use a GPS-based system in 2020 (DoT 2014). The more flexible congestion charges raise privacy concerns, however, as they rely on collecting commuters’ travel information (Parry et al. 2007).16

Several studies examine the effectiveness of congestion pricing designs. They include Olszewski & Xie (2005) (Singapore), Beevers & Carslaw (2005) (London), Simeonova et al. (2018) (Stockholm), and Gibson & Carnovale (2015) (Milan). These studies find that the schemes reduce congestion by about 10–30 percent and provide significant environmental benefits for the priced area.17 (For a review of studies on the impacts of existing congestion pricing schemes, see Anas & Lindsey 2011.18)

Congestion pricing has been rare in developing country. Two recent studies attempt to study the potential benefits of adopting such a policy in developing countries. Using real-time, fine-scale traffic data from Beijing, Yang et al. (forthcoming) analyze the relationship between traffic density and speed. They estimate the optimal time-varying and location-specific congestion charges to be between CNY 0.05 and CNY 0.39 per kilometer; they conclude that the

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15 Several dozen high-occupancy toll (HOT) lanes with variable or dynamic tolls are operating or planned in the United States. For example, the express lanes on Interstate 66 near Washington, DC, charge single-occupancy vehicles a fee that fluctuates according to traffic conditions.

16 Singapore’s electronic road pricing system features about 80 entry points that record passing vehicles around the city. The charges are not based on distance traveled, and they vary only infrequently. The system is being upgraded to a GPS-based system with the ability to incorporate time-varying and location-specific charges.

17 Drivers may respond to the charges by driving around the priced area. Such behaviors may lead to more traffic and emissions outside the area, as Gibson & Carnovale (2015) suggest.

18 Daniel & Bekka (2000), Bigazzi & Figliozzi (2013), and Fu & Gu (2017) study highway tolls and their environmental impacts. Using data from 98 Chinese cities, and both RD and DID methods, Fu & Gu (2017) show that eliminating highway tolls increases air pollution by 20 percent and decreases visibility by 1 kilometer.
pricing scheme could help relieve peak-hour traffic congestion and lead to annual welfare gains of CNY 1.5 billion.

With a similar focus but a different method, Kreindler (2018) uses GPS data on more than 100,000 commuter trips in Bangalore, India, to conduct a randomized experiment for the morning commute. He compares two congestion charge policies that impose fees for driving through certain areas during peak hours. Based on the experimental price variation, he estimates commuters’ preference for scheduling flexibility relative to their value of time. He concludes that the costs of rescheduling travel to inconvenient times will almost entirely offset the benefits of the saved travel time, resulting in only a small consumer welfare gain.

2.4 Ride-Sharing Services

Ridesharing services have become increasingly prevalent in many parts of the world. As travel demand and vehicle ownership increase in developing countries, encouraging ridesharing could potentially help combat severe air pollution and congestion. By increasing the flexibility of travel and providing a new travel mode, ridesharing could increase consumer surplus (Cohen et al. 2016). However, the impact of ridesharing on the environment hinges critically on the emissions of the substituted travel modes and on total travel demand.19 Leard and Xing (2020) estimate a discrete choice model of household mode choice using nationally representative data on travel behavior in the United States and simulating household mode choices in a setting where ridesharing was not available. They find that the availability of ridesharing has led to modest increases in total vehicle miles traveled and greenhouse gas emissions. Using survey results on Uber use by residents of Santiago, Chile, and Monte Carlo simulation, Tirachini and Gomez-Lobo (2017) find that unless ridesharing substantially increases the average occupancy rate of trips, ridesharing is like to increase vehicle kilometers traveled.

By exploiting the spatial and temporal variation of Uber entry and Uber penetration in the US market, Hall et al. (2018) estimate the impact of ridesharing on public transit ridership. They

19 If ridesharing mainly encourages carpooling and reduces private car driving, it may reduce overall on-road emissions. If the introduction of this new travel mode increases travel demand, or if ridesharing replaces walking or public transit trips, or if deadheading to search for customers (out-of-service movement) accounts for a significant component of vehicle miles, ridesharing may increase on-road pollution and impose new challenges to pollution reduction in the transportation sector.
find that Uber complements public transit by solving the last-mile problem of public transit. They suggest that ridesharing could worsen pollution and congestion by increasing the number of car trips without taking the substitution between ridesharing and private vehicle driving into account. However, if ridesharing complements public transit and encourages more consumers to switch from driving private cars to using public transits for the entire trip, ridesharing may help reduce the overall on-road tailpipe emissions and congestion.

Ridesharing may help mitigate air pollution and congestion through other channels. By better matching consumers and drivers, it reduces the time taxi drivers spend finding consumers. Reduced search time on the road could potentially reduce congestion and fuel consumption from the combined taxi and ridesharing market (Hahn & Metcalfe 2017). In addition, people who switch from driving private cars to ridesharing can save time and fuel wasted finding parking spaces, a problem in more populated cities (Winston 2013). The extent to which ridesharing reduces air pollution and congestion through these channels depends on the substitutability between ridesharing and private driving and taxi riding. Understanding the full impact requires estimating consumer travel mode choice incorporating ridesharing.

Further, there is a welfare effect of ridesharing: the use of idle capital leads to more efficiency. There is also a positive income effect that might lead to better options for fleet renewal and thus less pollutant cars. On the other hand, more mileage traveled by shared cars creates additional externalities such as potentially increased road safety issues. More research is required to understand the net welfare effect of ridesharing.

The implication from the literature is that to reduce traffic and pollution, ridesharing services must be integrated with the public transport system. This is not guaranteed under a free-for-all approach which is how peer-to-peer ridesharing services were first introduced. To create coordinated, “orchestrated” mobility ecosystems in which shared transport is integrated with public mass transit requires cities to take the lead in regulating ridesharing services and optimizing public transit investments (Gindrat 2020).

3 Policies to Promote Alternative Fuel Vehicles

The past two decades have witnessed the rapid development and diffusion of alternative fuel vehicle (AFV) technologies, amid heightened concern over energy security and transportation-related air pollution and GHG emissions. AFV technologies include flexible-fuel vehicles
(FFVs), hybrid vehicles (HEVs), battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), fuel cell vehicles (FCVs) and natural gas vehicles (NGVs). By reducing the consumption of gasoline and running on cleaner fuels, AFV technologies provide potential pathways to mitigate or even eliminate the environmental externalities associated with petroleum consumption.

AFV technologies face common adoption barriers in the early stage of diffusion, such as higher upfront costs, limited model choices, sparsity of vehicle refueling infrastructure, consumers’ lack of familiarity with the new technology, and the potential undervaluation of future fuel-cost savings. To help speed the diffusion of AFVs, governments in both developed and developing countries have provided various incentives to consumers and automakers. They include both monetary and nonmonetary incentives for purchasing AFVs and mandates and regulations that require automakers to produce AFV vehicles.

This section investigates the effectiveness of various policy tools as evidenced by the findings of recent studies of AFVs. Most of the empirical studies focus on markets in developed countries, but their conclusions and policy implications could to some degree be generalized to developing countries.

3.1 Subsidies for Adoption of Alternative Fuel Vehicles

The most widely used policies to stimulate the adoption of AFVs rely on tax credits and rebates. Tax credits are usually claimed on a tax return; rebates are either provided after mailing in a proof of purchase, or directly deducted upon purchasing an AFV. Governments can also implement vehicle scrappage schemes, in which buyers of energy-efficient vehicles receive rebates if they trade in their old emission-intensive vehicles (Li et al. 2013; Jacobsen & van Benthem 2015).

A large body of empirical studies estimates the effects of subsidies on consumer adoption of AFVs. The stated preference approach was especially popular during the early stage of the diffusion of alternative fuel technology because of the lack of data. A challenge of the stated preference analysis is that the hypothetical purchase environment is often different from the real world, and the choices that respondents make in a survey may not reflect their true preferences in a real vehicle purchase situation, biasing the elasticity estimates. With the increasing availability of sales data, and the adoption of real policies, recent studies have used the revealed preference
method by exploiting the spatial and temporal variation in market sales of AFVs and incentive policies while controlling for vehicle model characteristics and consumer demographic variables.

The effectiveness and efficiency of subsidy programs hinge on several factors. The first is the lack of additionality: the notion that incentives do not always result in additional AFV sales, because many buyers who receive the subsidy might still have purchased AFVs without it. This problem may be pronounced during the early deployment stage because early adopters of AFVs are consumers who embrace new technologies, and who have the strongest environmental awareness and, usually, higher incomes. Therefore, their purchase decisions do not heavily rely on the provision of subsidies; these people would probably have purchased AFVs without the subsidies.

Various empirical studies document the challenge of additionality. Chandra et al. (2010) argue that the HEV tax rebates offered by Canadian provinces subsidized many consumers who would have bought HEVs in any case. Bereseteanu & Li (2011) find that HEVs sales in the United States would still be growing rapidly, even without tax incentives. Huse & Lucinda (2014) find that a substantial share of FFV consumers in Sweden would have purchased FFVs in the absence of the cash rebates because of the vehicles’ lower operational costs. Xing et al. (2019) find that federal income tax credits for purchasing plug-in electric vehicles (PEVs) in the United States resulted in a 29 percent increase in PEV sales, but 70 percent of the credits went to households that would have purchased PEVs without the credits.

Replacing a one-size-fits-all policy with one that targets marginal buyers who are more responsive to the subsidy and would purchase AFVs only with the subsidy could improve effectiveness. Marginal buyers are those who consider the higher upfront cost the only obstacle to the adoption of AFVs, or those who view the subsidy amount as sufficient compensation for the utility loss from the other drawbacks of AFVs. Using the EV subsidy receipts data and vehicle transaction prices, Muehlegger & Rapson (2018) show that EV demand by low- and middle-income households is price elastic, and that the pass-through of the subsidy is complete among these consumers. Xing et al. (2019) find that cost effectiveness is greater for policies that that eliminate or reduce subsidies for high-income households, and provide more generous

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20 Plug-in electric vehicles (PEVs) include both battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs).
21 See DeShazo (2016) for a literature review on the effectiveness of US subsidy programs for plug-in electric vehicles.
subsidies for low-income households. Improving the targeting of the subsidy policies is an important issue and an active area of research in other energy and poverty-reduction programs (Allcott et al. 2015; Kitagawa & Tetenov 2018).

The second important factor is the need to design a subsidy that pays attention to the heterogeneity in benefits across locations and vehicles. Although PEVs produce little or zero tailpipe emissions on the road, substantial heterogeneity of environmental impacts could exist when factoring in upstream emissions. The environmental advantage of PEVs over conventional vehicles is lower in locations where electricity is generated through fossil fuels. Holland et al. (2016) find considerable heterogeneity in the environmental benefits of PEV adoption in the United States, depending on the location. They therefore argue for a regionally differentiated PEV policy. The environmental benefit of PEVs is the largest in California, where the damage from gasoline vehicles is great, and the electric grid is relatively clean. In contrast, PEVs cause more harm than gasoline vehicles in places such as North Dakota, where electricity is generated mostly from coal. For the many developing countries that rely on coal for electricity generation, the environmental benefit of PEVs is an important empirical question.

A third factor to consider in policy design is the fact that the environmental benefits of AFVs hinge on the amount of gasoline replaced by alternative fuels. This figure is challenging to estimate because consumers who choose to buy AFVs may be different from others in driving demand. Consumers who purchase AFVs may have greater environmental awareness; they may thus have purchased another fuel-efficient vehicle had they not purchased an AFV. As a result, the reduction in emissions may be small (Xing et al. 2019). In addition, the ability of AFVs to reduce pollution depends on how many miles AFVs are driven and how many miles would have been driven by gasoline vehicles. Because they have a shorter range and charging is inconvenient, BEVs may not be driven as much as conventional vehicles. Davis (2019) finds that both BEVs and PHEVs are driven considerably fewer miles per year than gasoline vehicles, possibly due to the so-called range anxiety, and suggests that PEVs may therefore imply smaller environmental benefits than previously believed.

For AFVs, such as FFVs and PHEVs, that piggyback on gasoline vehicles and can run on both gasoline and alternative fuels, “fuel arbitrage” could also weaken the effectiveness of subsidies in reducing emissions. With relatively low gasoline prices, FFV and PHEV drivers are more incentivized to choose gasoline or diesel over ethanol or electricity, given the lack of
ethanol and electric fueling infrastructure, and the inconvenience of refueling. Huse & Lucinda (2014) estimate that CO$_2$ savings would fall by 14 percent if gasoline usage among FFV drivers increased to 50 percent, and by 18 percent if such gasoline usage increased to 75 percent. Salvo & Huse (2013) find imperfect substitutability between gasoline and ethanol among flexible-fuel motorists in Brazil because consumers discriminate among fuel options based on characteristics other than price, including engine performance, the station-stopping cost, and the origin of the fuel. They suggest that substantial investments in consumer education on less-established alternative fuel technologies are required because consumer demand for the “incumbent” gasoline is sticky.

To summarize, when designing AFV subsidy policies, policy makers need to account for fuel-switching behaviors and alternative fuel usage. Both factors affect the effectiveness of such policies in reducing emissions. One possible solution is to adjust the AFV subsidy amount based on the frequency of alternative fuel usage when such data are available. Providing valuable fuel price information and accessible price comparison could increase the usage of alternative fuels (Salvo 2018).

It should be noted that the adoption of EVs also offers energy saving benefits. Regardless of the fuel mix of electricity generation, EVs are much more efficient in converting energy than traditional internal combustion models. According to the US Department of Energy, “EVs convert about 59 percent–62 percent of the electrical energy from the grid to power at the wheels. Conventional gasoline vehicles only convert about 17 percent – 21 percent of the energy stored in gasoline to power at the wheels”. In addition, simulation analysis shows that EVs can reduce the peak capacity needed from the grid if vehicles with charged batteries transfer some of their stored energy back to the grid during times of high demand, a process known as Vehicle to Grid (V2G) (Tse et al 2016). Peak shaving not only reduces overall cost of demand charges but also reduces the investment needs for building reserve capacities of electricity network.

### 3.2 Subsidies for Alternative Fueling Infrastructure

FFVs and PHEVs can be fueled at any gasoline station. The diffusion of other AFVs relies heavily on alternative fueling infrastructure, which is limited during the early deployment stage. The interdependence between the building of fueling stations and the adoption of AFVs gives
rise to the “chicken and egg” problem: Consumers are reluctant to adopt AFVs unless there are sufficient alternative fueling stations, but governments and private companies are reluctant to build such stations when few AFVs are on the road. The installation of home charging for PEVs could reduce dependence on public fueling stations; the fueling of FCVs depends entirely on public hydrogen stations.\(^\text{22}\) For 3-wheelers replaceable portable batteries could also be an option.

In addition to providing subsidies to AFV buyers, many governments have been subsiding the building of AFV fueling stations. It is important to understand whether subsidizing one side of the market is more efficient than subsidizing the other side. Dimitropoulos et al. (2016) find that early adopters of PHEVs are sensitive to changes in the detour time to reach a fast-charging station. They argue that policies that expand fast-charging stations could be an effective stimulus for the early adoption of BEVs, potentially saving public spending for the stimulation of the adoption of electric vehicles.

Li et al. (2017) and Springel (2019) quantify the indirect network effects in the PEV market in the United States and Norway, respectively. Both studies find that the network effects of charging stations on PEV adoption are larger than the effects of PEV stock on investment in charging stations; they therefore suggest that subsidizing charging stations is more effective in speeding PEV diffusion at the initial rollout stage. This finding is likely driven by the fact that early adopters are less price-sensitive, and more concerned about whether they can conveniently refuel wherever they drive.

At the early stage of a technology deployment, the existence of multiple standards of the complementary service may lead to efficiency loss. Li (2019) finds that unifying the three incompatible standards for charging EVs in the United States would have increased consumer surplus by USD 500 million between 2011 and 2015, and allowed car manufacturers to sell 20.8 percent more EVs.

4 Fuel Standards and Emissions Regulation

Instead of directly providing incentives to alter consumer vehicle purchase and driving behavior, governments can impose mandates and regulations on vehicle producers to reduce pollution.

\(^{22}\) FCVs are powered by hydrogen and fueled with pure hydrogen gas from hydrogen fueling stations. They can fuel in less than 10 minutes and have a driving range of about 300 miles. As of October 2019, there were only 41 hydrogen stations in the United States. The FCV market will not witness significant penetration unless the mass deployment of hydrogen stations occurs.
This section discusses the main mandates on manufacturers: fuel-economy standards, fuel-content regulations, and tailpipe emission standards.

4.1 Fuel-Economy Standards

Many countries adopted fuel-economy standards that require vehicle manufacturers to improve fleet-wide fuel efficiency and provide a minimum level of alternative fuel vehicles. Nine governments, including the United States, Japan, the European Union, and China, have established fuel-economy and GHG emission standards for passenger vehicles. The standard an automaker needs to meet is usually a (sales-) weighted average of the target for each vehicle model in the automaker’s fleet. Automakers who fail to meet the requirement either pay the penalty or buy regulatory credits from the market under the credit-trading regime.23

One argument that supports fuel-economy regulations is that consumers may undervalue fuel economy and fail to adopt fuel-saving technologies. The empirical literature has mixed evidence on the extent to which consumers discount future fuel-cost savings (Busse et al. 2013; Allcott & Wozny 2014; Sallee et al. 2016; Grigolon et al. 2018). Studies that evaluate the efficiency of fuel-economy regulations in reducing gasoline consumption consistently find that gasoline taxes can achieve the same goal at a much lower cost (Goldberg 1998; Austin & Dinan 2005; Jacobsen 2013; Anderson & Sallee 2016).

However, due to the political challenge of increasing taxes and the difficulty of quantifying the marginal social harms, the external cost of gasoline consumption in many countries around the world is not properly reflected by the gasoline tax (Parry & Small 2005, Parry & Timilsina 2010, Parry & Timilsina 2015). If the regulator decides to implement fuel-economy mandates, there are several lessons from the literature that are relevant for developing countries. First, with a binding fuel-economy mandate, providing additional AFV subsidy may have little impact on reducing energy consumption or GHG emissions. Fuel-economy mandates essentially increase the cost of producing vehicles that are less fuel efficient, and encourage automakers to sell more AFVs. However, when the additional AFV subsidy induces extra AFV

23 In addition to establishing fuel-economy mandates, some governments require that a certain share of the entire fleet each automaker sells be zero emission vehicles (ZEVs). California, for example, requires that 4.5 percent of vehicles produced be ZEVs in 2018, and 22 percent be ZEVs by 2025.
sales, the mandate stringency is relaxed, and automakers can thus sell more gasoline vehicles and still maintain compliance. Therefore, the AFV subsidy implicitly subsidizes gas-guzzlers, as it makes it easier to sell them. One possible solution is to exclude AFVs from the average fleet fuel-economy calculation so that the mandate takes only gasoline vehicles into account. Second, the fuel-economy mandates in many countries are now attribute based; the stringency of the regulation depends on the vehicle’s weight or size, and larger and heavier vehicles are subject to a less-stringent requirement. However, this policy design provides incentive for automakers to increase vehicle size, which could undermine the gains from fuel economy (Ito & Sallee 2018; Whitefoot & Skerlos 2012). Policy makers should be aware of the potential for vehicle substitution across sizes to occur when assigning fuel economy targets for different vehicle segments.

4.2 Fuel-Content Regulations and Tailpipe Emission Standards

Implementing fuel-content regulations that restrict the chemical composition of the fuel is another strategy to reduce the harmful pollutants from fuel consumption. Most developed countries enforce the European Union’s Fuel Quality Directive, which requires sulfur levels below 10 parts per million for both gasoline and diesel vehicles. In contrast, many developing countries still set sulfur limits above the level recommended by the United Nations.

When designing these policies, regulators should be mindful of firms’ responses and unintended consequences. Auffhammer & Kellogg (2011) find that the US federal gasoline content regulation, which allowed refiners flexibility in choosing a compliance mechanism, did not improve air quality because refiners lacked incentives to reduce the emission components that are most closely related to ozone formation. By contrast, the standards used in California that better target harmful components are more effective in improving air quality.

Emissions-control systems can be installed that reduce tailpipe emissions per gallon of fuel combusted. Tailpipe emission standards set the maximum amount (grams per mile) of targeted pollutants allowed in exhaust emissions from a fuel combustion engine. A number of countries – including the United States, Canada, Japan, the European Union, China, and India – have implemented this type of regulation. Tests conducted at specified intervals measure vehicle emissions, typically PM, NOx, CO, and hydrocarbons. Under such regulations, manufacturers may only sell vehicles that comply with standards. In the United States, the EPA manages and
implements emission standards. California is allowed to implement more stringent emission standards, which are set by the California Air Resources Board (CARB).

In 2000, both China and India introduced their first emission standards, based on European regulations of that time. Since then both countries have tightened their standards several times to address serious air pollution in urban areas. Based on the most more stringent European standards (Euro 6) already imposed in the EU, the new standards are slated to go into effect in 2020 in both China and India. The effectiveness and efficiency of these policies remain to be studied.

5 Conclusions and Future Research Areas

Many developing economies, especially rapidly growing ones, are facing pressing environmental challenges due to the increased demand for fossil fuel-based urban transportation, and the lack of effective and stringent regulations on pollution control. As income rises in these countries, demand for environmental quality increases, putting pressure on governments to reevaluate their positions on managing urban mobility and environmental quality (Fouquet 2012).

The first best solution for managing the potential trade-off between mobility and air pollution comes down to managing urban space. Private autos are the most inefficient use of transportation space, while non-motorized mobility such as walking and cycling, and mass transit modes is the most efficient use of transportation space. Land-use planning affects individuals’ choice of travel modes. Simulation analysis shows that land use policies that favor a compact city in which land density and diversity were increased and distances to public transport were reduced can get more people out of private cars into non-motorized mobility and mass transit, representing the most promising way to reduce air pollution and urban congestion (Stankov et al. forthcoming).

Beyond land-use and transportation planning policies, an alternative suite of policies focuses on reducing vehicle miles traveled per capita and tailpipe emissions per mile of driving. These policies include driving restrictions, congestion pricing, shared mobility, fuel tax, subsidies for alternative fuel vehicles, fuel-economy standards and emissions regulation. Because most studies on land-use change and its impact on transportation are based on computer
simulations, this paper reviews the effectiveness of the second set of policies for which more empirical studies on their causal impact on the environment are available. These policies and their pros and cons based on the literature review are summarized in Table 2. A more complete reference summarizing the methodological features and empirical highlights of each study is found in the appendix.

Table 2 Transportation policies aimed at addressing air pollution issues

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<tr>
<th>Policies</th>
<th>Pros</th>
<th>Cons</th>
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<tbody>
<tr>
<td><strong>Supply-side policies (infrastructure investment and regulation on vehicle producers)</strong></td>
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<td><strong>Expansion of public transit</strong></td>
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<tr>
<td>• Building new roads, highway expansion</td>
<td>• More travel mode choice</td>
<td>• High cost of investment</td>
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<tr>
<td>• Expand subway system, bus system</td>
<td>• Divert marginal automobile travelers, which could potentially reduce congestion and air pollution</td>
<td>• Reducing travel cost could lead to additional driving and congestion.</td>
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<tr>
<td>• Making public transportation faster and more advanced: BRT, light rail</td>
<td>• Stimulate economic activities and facilitate trade</td>
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<tr>
<td><strong>Fuel-standards and emission regulations</strong></td>
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<tr>
<td>• Fuel-economy standards</td>
<td>• Reduce gasoline consumption</td>
<td>• Less cost-effective than gasoline taxes</td>
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<td></td>
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<td>• Less effective when subsidies for alternative fuel vehicles relax mandate stringency</td>
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<td></td>
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<td>• Attribute-based fuel-economy standard (larger and heavier cars are subject to a less stringent regulation) could cause automakers to make larger cars</td>
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<tr>
<th>Policies</th>
<th>Pros</th>
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<tr>
<td><strong>Demand-side policies (two margins: driving behavior, and vehicle demand behavior)</strong></td>
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<td><strong>Command-and-control policies</strong></td>
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<td><strong>License-based driving restrictions</strong></td>
<td><strong>Could reduce car traffic</strong></td>
<td><strong>Requiring complementary policies to avoid drivers purchase older and dirtier second vehicles</strong></td>
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<tr>
<td><strong>Purchase restrictions based on auction or lottery system</strong></td>
<td><strong>Generate substantial revenue (auction)</strong></td>
<td><strong>Lottery system leads to a large welfare loss from misallocation</strong></td>
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<td><strong>Ban on second-hand vehicle trade</strong></td>
<td><strong>Could reduce lifetime emissions</strong></td>
<td><strong>Reduce welfare gains from trade</strong></td>
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<td></td>
<td></td>
<td><strong>Could increase average emissions per vehicle if imported used cars are cleaner than domestic cars</strong></td>
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**Market-based policies**

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<thead>
<tr>
<th><strong>Congestion pricing</strong></th>
<th><strong>Reduce congestion</strong></th>
<th><strong>Increase average travel time or lead to travel time shifts, causing welfare loss</strong></th>
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<tbody>
<tr>
<td></td>
<td><strong>Increase car-pooling and public transport usages</strong></td>
<td><strong>Difficult to determine location and time-specific optimal congestion pricing due to technical feasibility and political acceptability.</strong></td>
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<td></td>
<td><strong>Generate substantial revenue (eg: Congestion tax) which can be used to improve access to and the quality of public transit.</strong></td>
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<table>
<thead>
<tr>
<th><strong>Subsidies for adoption of alternative fuel vehicles (AFV)</strong></th>
<th><strong>Reduce local air pollution</strong></th>
<th><strong>High fiscal cost</strong></th>
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<td></td>
<td><strong>Reduce greenhouse gas emissions in areas where renewables are the main source of electricity</strong></td>
<td><strong>Limited additionality especially because (1) early adopters are not price sensitive and would purchase AFVs even without subsidies, (2) customers who purchase AFVs may have greater environmental awareness and may purchase fuel-efficient vehicles had they nor purchased an AFC</strong></td>
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<tr>
<td></td>
<td></td>
<td><strong>Difficult to determine subsidy levels that reflect heterogeneity in AFV’s benefits across location and vehicles</strong></td>
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<td></td>
<td></td>
<td><strong>Electric vehicles may generate limited environmental benefits</strong></td>
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A few lessons can be drawn from the literature review. First, the current studies are rather restricted in their scope and there is inadequate empirical evidence on the effectiveness of transportation policies in low-income, low-motorized countries. This partially reflects a selection bias, i.e. studies tend to focus on cities where the most innovative and radical measures to control congestion and pollution have been adopted. These cities tend to be in developed countries with high motorization rates.

Second, because developed and developing countries vary significantly across socioeconomic and geographic attributes of their respective urban areas, caution should be taken to generalize findings from developed to developing countries. For example, the effect of public transit supply on auto travel volumes is subject to considerable variability and is dependent upon population density, motorization rates, existing public transit networks and so on. While there is modest evidence that public transit expansion helped reduced congestion levels and air pollution in developed countries, analyses must be carried out on a case-by-case basis in developing countries to verify the cost and benefit of public transit investments.

Third, market-based policies such as congestion pricing have efficiency advantages over command-and-control approaches in addressing the externalities associated with transportation.
Their applications have been very limited, however, especially in developing countries (Timilsina and Dulal 2011, Berg et al. 2016). This is due to both political barriers and lack of technical capacity in designing and implementing price instruments (Stavins 1997). Standards produce rents. For this reason, industries and consumers prefer command-and-control standards to taxes. Legislators also typically prefer command-and-control standards because standards tend to hide the costs of pollution control while emphasizing the benefits.

Fourth, complimentary policies are often needed to avoid unintended consequences of command-and-control policies. The literature shows that command-and-control approaches were often unsuccessful at inducing drivers to substitute away from private vehicles. Notably, the benefits of public transit provision and driving restrictions could be greatly improved by devising economically and politically acceptable approaches to efficiently pricing auto travel.

Future research could shed further light on the pros and cons of different policy instruments while paying attention to not only the efficiency and distributional impacts of existing policies, but also to the emerging opportunities afforded by new technologies and practices. The following questions warrant future research.

First, understanding how consumers in developing countries value fuel economy could help policy makers estimate the efficiency and effectiveness of policy tools such as gasoline taxes and fuel-economy standards to incentivize the purchase of fuel-efficient vehicles. This question is especially important for developing countries, where many vehicle buyers are first-time buyers, and information on fuel economy may not be well understood. If consumers are not well informed, or if they do not pay attention to fuel cost, they may choose vehicles that are less fuel efficient than optimal, providing a justification for government intervention through fuel-economy regulations. As discussed in Section 4.1, there is no consensus on the extent to which consumers undervalue fuel economy in developed countries. Even less evidence is available on

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24 Even when fully informed about the fuel economy of each vehicle model, consumers may not have the correct perception of the monetarized value of fuel economy, because of “MPG Illusion,” in which consumers mistakenly think that fuel costs scale linearly in miles per gallon rather than gallons per mile (Larrick & Soll 2008). The estimated welfare cost of the “MPG Illusion” is negligible, however, and is not sufficient to justify the current fuel economy regulations (Allcott 2013). Using data from experiments that provide fuel economy information to new vehicle buyers in the United States, Allcott & Knittel (2019) find no impact of the information intervention on consumers’ vehicle choices; the authors suggest that US fuel economy standards are more stringent than necessary in addressing imperfect information.
this issue in developing countries (Greene 2010). Chugh et al. (2011) find no strong evidence that consumers undervalue fuel economy in India. Comparing the vehicle consumption tax and fuel tax in China, Xiao & Ju (2014) find that increases in the fuel tax decrease total car sales but do not effectively encourage consumers to choose fuel-efficient vehicles. When choosing vehicles, consumers are more sensitive to changes in upfront costs than fuel costs. Further studies are needed to understand consumer preferences, information access, and awareness of fuel economy in developing countries.

Second, new technologies related to transportation could offer opportunities as well as challenges for developing countries in addressing environmental issues. Autonomous vehicles have the potential to profoundly transform the transportation sector and the economy in general (Winston & Karpilow 2019). However, a decade may pass before these vehicles comprise a significant share of the overall vehicle fleet. Thus, related empirical data may not be available for many years.25

Third, transportation policies could have broad social and economic impacts by changing a variety of household choices. Previous studies have shown that changes in commuting cost can affect labor participation decisions, fertility, and productivity (Black et al. 2014; Duranton & Turner 2012; Liu et al. 2018). Few studies have examined the broad impacts of transportation-related policy beyond immediate goals, especially in developing countries. Understanding household location choices and the general equilibrium impacts of transportation policies could help policy makers better understand their impacts on the environment and urban structure, as well as the distributional consequences. Transportation innovations and policies such as infrastructure expansion and congestion pricing affect the commuting cost and household location choices, as predicted by classical urban models (LeRoy & Sonstelie 1983). The spatial pattern of household locations in turn affects travel choices (travel mode and distance) and the environment. To examine these questions, researchers can employ equilibrium sorting models that incorporate consumer heterogeneity and allow for general equilibrium feedback between economic agents and the environment (Epple & Sieg 1999; Kuminoff et al. 2013; Sieg et al. 2004). These types of models can shed light on the interactions between transportation policies

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25 Researchers would need to use projections and simulations to conduct forward-looking analysis on how autonomous vehicles would affect travel behavior, vehicle choices, housing locations, and the broad economy.
and housing markets and provide a unified framework with which to analyze and compare the effectiveness of different transportation policies to address the environment, traffic congestion, and social welfare.

Fourth, future research needs to devote more attention on policies aimed at addressing externalities associated with informal public transport and two-wheeler vehicles which are unique challenges in developing countries. Informal public transport and two-wheelers such as motorcycles are fundamental means of mobility especially for the poorest segments of the population in developing countries due to their lower costs and their ability to transfer commuters closer to their destinations regardless of the road quality (Collier et al, 2019; Shimazaki & Rahman, 1995; Yanez-Pagans et al, 2018).

Many of the policies discussed in the paper are suitable for mitigating emissions from two-wheeler vehicles. Addressing negative externalities from informal transport operations is more challenging. Simply banning informal transport or replacing it with formal counterparts is unlikely to be successful given the complementarity characteristic of the informal modes of transport. It is important to note that informal vehicles are sometimes the only option commuters have due to limited resources and capacity constraints of the government. India is a good example of this. The Indian government provides bus- and rail-based public transport services in only 65 cities among 7,935 cities and towns. In the rest of the places, people’s mobility needs to non-walking distances are met through personal vehicles and informal transport (Kumar et al, 2016).

In order to improve the overall public transport services by maintaining and improving vehicles, working with informal providers and combining regulation with finance might benefit developing countries. Collier et al (2019) discuss cases in Lagos, Nigeria, and Ghana where the governments provided the finance or financial guarantees that allowed existing informal vehicle owners to form cooperatives and jointly invest in higher capacity buses. Including minibus taxi operators into negotiations for the new bus rapid transport system in Johannesburg, South Africa also positively contributed to engaging all actors in the new system.

References


United States Department of Transportation. The Smart/Connected City and Its Implications for Connected Transportation. White Paper FHWA-JPO_14-148


### Appendix Summary of main articles reviewed in the paper

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**Restrictions on Driving and Vehicle Purchase**

<p>| Wolff (2014)           | Germany                   | 2008-2010   | Air quality (half-hourly, hourly, daily), location information of stations, and low emission zones | Difference-in-differences     | Low Emission Zones decrease air pollution by around nine percent in urban traffic centers while |</p>
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which would increase traffic safety risks

**Fuel-Content Regulations and Tailpipe Emission Standards**

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**New technologies (ride-sharing)**

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