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The Future of Transportation Fuels and Vehicles

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Thank you, Chairman Shimkus, Ranking Member Tonko, and distinguished members of the Subcommittee, for inviting me to speak today. My name is Joshua Linn. I am an Associate Professor in the Department of Agricultural and Resource Economics at the University of Maryland, and a Senior Fellow at Resources for the Future (RFF), a nonprofit and nonpartisan environmental economics think tank.[1] My research focuses on how consumers choose their vehicles and how much to drive, and how automakers choose technology.

New technologies are fundamentally changing the vehicles people buy and the way they travel. Each year, passenger vehicles become more efficient, safe, and fun to drive. New car buyers can choose among an expanding number of plug-in vehicles, in addition to the more familiar gasoline, hybrid, and diesel options. Information technologies continue to create new travel options, such as ride-sharing services and bike-share programs. The future may bring ever-increasing levels of automated driving, further benefiting consumers. At the same time, policies to promote innovation and new technologies exist at both federal and state levels—including standards for vehicle fuel economy and greenhouse gas emissions, tax credits for plug-ins, and subsidies for infrastructure and research.

These are exciting technological developments, which will benefit the US economy. However, their implications for energy security and the environment are more complex.

[1] RFF is an independent, nonprofit research institution focused on environmental, energy, and natural resource economics and policy. The opinions I express today are my own, and represent positions of neither the University of Maryland nor RFF.

On the one hand, innovations that reduce fuel consumption help us improve energy security and the environment. New information technologies make the transportation system more efficient. On the other hand, these same technologies may lead to more driving, higher fuel consumption, and increased emissions. Fortunately, well-designed policies can simultaneously foster innovation that benefits society while meeting energy and environmental policy objectives.

I'll make three additional points:

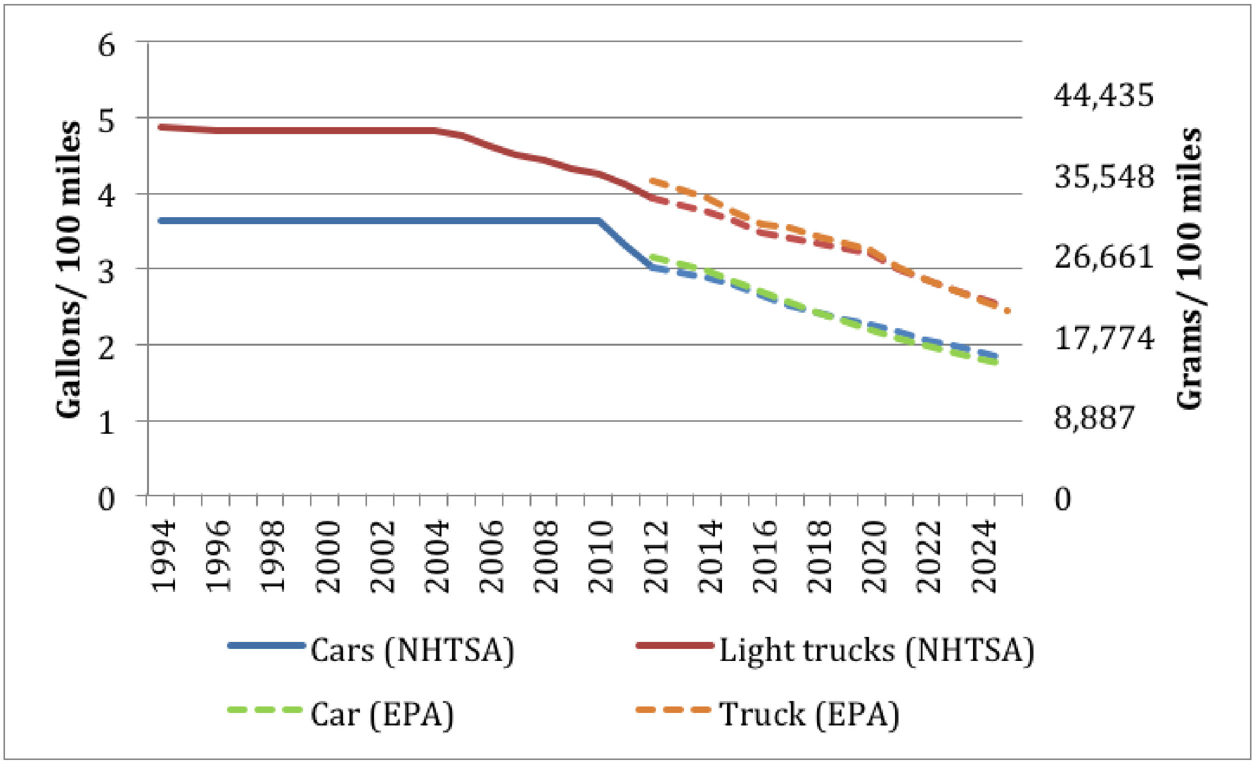
1. *So far, tightening standards for fuel economy and greenhouse gas emissions have imposed modest costs on automakers and consumers, and benefits likely exceed the costs*. Consumers do not appear to fully value the fuel cost savings from higher fuel economy, causing automakers to absorb some of the costs of the standards. Tighter standards have driven technology adoption and affected vehicle attributes other than fuel economy, such as horsepower.
2. *Gasoline-powered vehicles are likely to continue dominating the market for some time*. Presently, subsidies are largely driving the plug-in vehicle market. In the future, declining battery costs and improving vehicle quality will surely boost sales, but it is very difficult to say how much and how quickly.
3. New travel options are changing how people get around. *Adjusting the structure of fuel economy and greenhouse gas standards to reflect vehicle usage can ensure that policy objectives continue to be met*.

Background: Greenhouse Gas Standards

To provide historical context, Figure 1 shows the fuel economy standards (managed by the National Highway Traffic Safety Administration, NHTSA) and greenhouse gas emissions standards (administered by the Environmental Protection Agency, EPA) for cars and light trucks from 1994 through 2025. These standards were essentially flat between the late 1980s and the mid-2000s, and average fuel economy and greenhouse gas emissions rates did not change much during those years. Standards have been tightening since 2005 for light trucks and 2011 for cars, meaning higher fuel economy, lower fuel consumption rates, and lower emissions.

Under current regulations, fuel economy would roughly double between 2011 and 2025. That's a dramatic change after a long period of stasis.

Figure 1. Fuel Economy and Greenhouse Gas Standards, Historical and Projected



Source: Leard and McConnell (2017).

Consumer Demand for Fuel Economy

Tighter standards cause automakers to adopt fuel-saving technology, increasing fuel economy and reducing greenhouse gas emissions. In this section and the next, I focus on gasoline-powered vehicles, which currently account for about 99 percent of the US market. Here, I discuss how fuel-saving technology affects consumers.

Suppose an automaker increases a vehicle's fuel economy without changing anything else about the vehicle, and the higher fuel economy saves the consumer $100 in fuel costs over the vehicle's life. If the consumer is willing to pay less than $100 for the increase in fuel economy, *undervaluation* is at play—the consumer undervalues the cost savings from higher fuel economy.

Undervaluation has important implications for how standards affect consumers. Suppose that the technology costs $90 and saves consumers $100 in fuel costs. If consumers are willing to pay less than $90 for the technology, the automaker won't be able to recoup its related costs and it won't add the technology. That's a market failure because society would be better off if the automaker raises fuel economy; the value of the fuel savings ($100) exceeds the cost of the technology ($90). This market failure is often referred to as the energy efficiency gap, or energy efficiency paradox.

Because of this market failure, standards for fuel economy (or greenhouse gas emissions) could make consumers better off. Essentially, standards "correct" the mistake that consumers make and compel automakers to offer higher fuel economy. In other words, undervaluation would provide a justification for regulating fuel economy and greenhouse gas emissions, even if one ignores the societal costs of fuel consumption and emissions (for example, regarding energy security, climate, etc.).

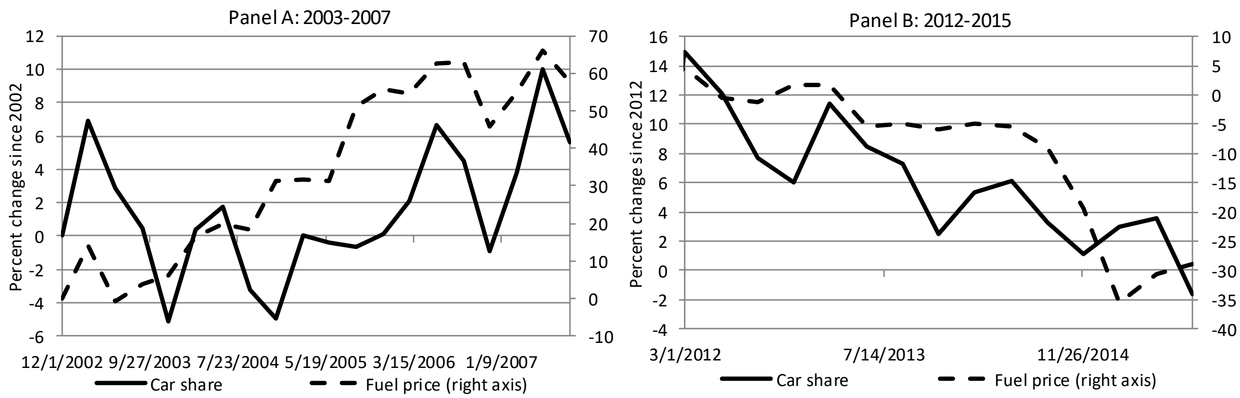
The EPA and NHTSA claim that this market failure exists. Their argument is largely based on the observation that automakers do not appear to adopt fuel-saving technologies as quickly as one would expect, given the estimated costs and fuel savings of those technologies. As summarized in a few reports by the National Research Council, an extensive literature analyzing technology costs and fuel savings supports this argument.[2]

There's also quite a lot of evidence that gas prices affect consumer vehicle choices.[3] When gas prices go up (like they did in the mid-2000s), consumers shift from new light trucks to new cars; when gas prices go down (like they did between 2014 and 2015), consumers shift from new cars to new light trucks. Figure 2 depicts these patterns, and recent research has shown that gas prices affect consumer choices among individual vehicle models as well.

[2] For example, see National Research Council (2015).

[3] Many studies demonstrate strong links among gasoline prices, new vehicle purchases (e.g., Klier and Linn 2010), scrappage of older vehicles (Jacobsen and van Benthem 2015), and overall fuel economy of the on-road fleet (Li et al. 2009).

Figure 2. Fuel Prices and Market Share of New Cars (Percent Changes)



Source: Calculations using data from Wards Auto and US Bureau of Labor Statistics.

The fact that sales respond to gas prices is relevant, but it does not exactly answer whether consumers undervalue fuel economy. This is a harder question to answer—and up until a few years ago, the evidence was all over the place.[4] Then, based on gasoline price changes in the 1990s and early 2000s, several high-quality studies concluded that consumers fully or nearly fully value fuel economy, for both new and used vehicles.[5]

However, newer evidence suggests that consumers undervalue recent improvements in fuel economy. Over the past decade, automakers have gradually added fuel-saving technology and raised fuel economy to meet tightening standards. For example, between 2013 and 2014, Honda installed a continuously variable transmission in the Honda Civic EX-L, which raised fuel economy from 31.5 miles per gallon to 32.3. (This type of transmission matches the engine and wheel speeds more efficiently than a conventional transmission.) Many other examples like this one exist, and we can ask how much consumers typically pay for the higher fuel economy. Based on data covering about a half million recent new vehicle buyers between 2010 and 2014, on average, consumers pay about $50 for $100 of fuel savings.[6] Note that consumers get the full benefit of the higher fuel economy, by way of lower fuel costs—it's just that they're not willing

[4] See Helfand and Wolverton (2009) for a review of the literature.
[5] See Busse et al. (2013), Allcott and Wozny (2014), and Sallee et al. (2016).
[6] See Leard et al. (2017).

to pay for the full value of the savings. This may be because they're not aware of the savings, or for other reasons.

Consumer undervaluation suggests that fuel economy standards can address the market failure for fuel economy. It also implies that automakers have a hard time passing on the costs of the standards to consumers. The EPA and NHTSA assume that when automakers adopt fuel-saving technology, they raise vehicle prices sufficiently to cover costs. But if consumers only pay half the value of the fuel savings, and the technology costs more than consumers are willing to pay, automakers have a difficult choice to make. The first option is to raise vehicle prices to cover their costs. This would cause consumers to choose other vehicles, because they don't think the price increase is worth the fuel savings (even though it is actually worth the savings). Vehicle sales and profits would decrease. The other option is to raise vehicle prices by the amount consumers are willing to pay, absorbing the difference between the technology costs and price increase. For example, if it costs $90 to raise fuel economy enough to save consumers $100, automakers will raise vehicle prices to cover $50 of those costs, incurring a loss of $40. In either case, automaker profits decrease. Thus, undervaluation implies that the costs of tighter standards for fuel economy are borne by both consumers and automakers.

Fuel-Saving Technology, Vehicle Attributes, and the Costs of Greenhouse Gas Standards

This section considers the total costs of the greenhouse gas standards. I'll discuss how the standards affect automaker technology choices, and summarize some recent evidence on the costs of the standards.

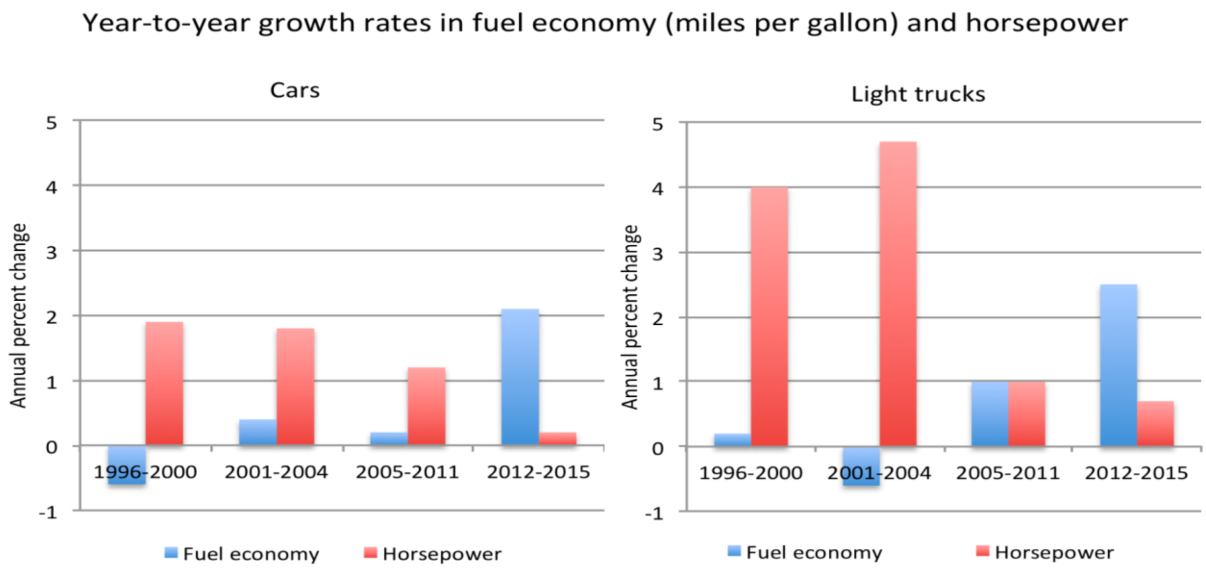
An automaker that adds fuel-saving technology to one of its vehicles must decide how to integrate that technology and choose the vehicle's fuel economy and horsepower. Suppose an automaker has a vehicle for which it is considering adding fuel-saving technology. For example, a technology called cylinder deactivation can improve the efficiency of large engines by shutting off some of the cylinders when the vehicle is under light load. Automakers have recently added this technology to many light trucks, but let's suppose that the particular vehicle in this example does not have it. Typically, we think that when the automaker adds a technology such as this one, it uses the technology to raise fuel economy, while leaving other attributes (such as horsepower) unchanged. But it doesn't have to do this. Instead, the automaker can add the technology, and then make further changes to the engine or transmission that effectively result in higher horsepower without changing fuel economy (compared to the initial vehicle). In other words, the automaker improves the vehicle's efficiency when it adds the fuel-saving technology. The automaker can decide whether to use the additional efficiency to boost fuel economy, horsepower, or both.

Given this flexibility to choose between horsepower and fuel economy, what do automakers actually do? Typical consumers are willing to pay more for horsepower than for an equivalent amount of fuel economy. Consequently, during times when the standards weren't changing, automakers adopted fuel-saving technology and used the added efficiency to boost horsepower while leaving fuel economy unchanged. For example, the National Museum of American History has an early version of the Honda Civic from the 1980s—it was tiny compared to today's Civic. The early Civic and today's version get similar levels of fuel economy, but today's Civic is much larger and has roughly double the horsepower because of all the technology that Honda has added over the past 30 years.

However, tighter standards change the automaker's incentives. With tighter standards, when an automaker adds technology it now has a greater incentive to use the technology to boost fuel economy. Therefore, with tighter standards, automakers are more inclined to use fuel-saving technology to boost fuel economy than when standards are held constant.

Figure 3 shows exactly these patterns, illustrating changes in horsepower and fuel economy for cars and light trucks, between 1996 and 2015. Standards for cars didn't change from 1996 through 2011, and during that time automakers raised horsepower by about 2 percent per year on average, leaving fuel economy basically unchanged. Then, when standards began tightening in 2012, fuel economy increased 2 percent per year, and horsepower didn't change at all. Light trucks show a similar patter, where the standards began tightening in 2005. Essentially, tighter standards caused fuel economy to improve rather than horsepower, implying that tighter standards caused consumers to forgo the horsepower improvements they would have enjoyed if standards hadn't tightened. Several recent studies quantify the magnitude of these costs to consumers from the forgone horsepower improvements, finding them to be on the order of several billion dollars per year (compared to fuel savings of roughly $20 billion per year).[7]

Figure 3. Historical Changes in Fuel Economy and Horsepower



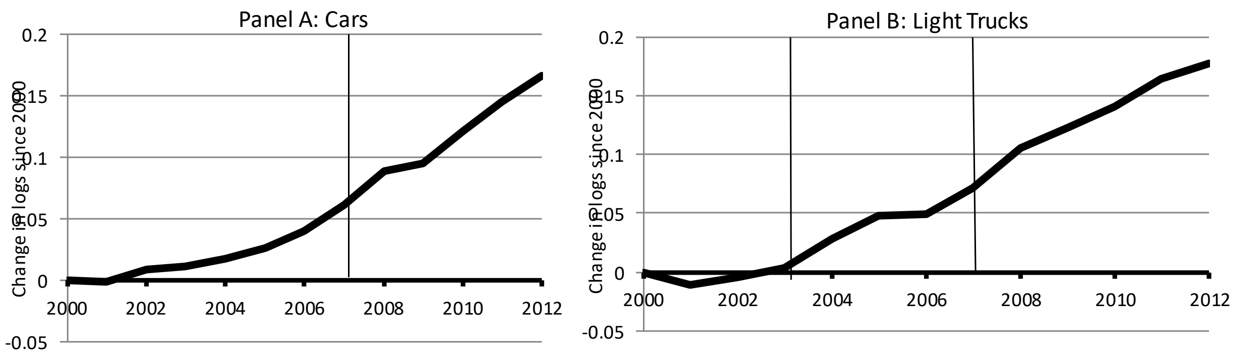
Source: Calculations from Wards Auto data.

Tighter standards also cause automakers to adopt fuel-saving technology more quickly. Adding technology raises vehicle costs, and when standards are unchanging automakers add technology if they think consumers are willing to pay for the higher horsepower (or other attributes). When standards are tightening, they create an additional incentive for automakers to add fuel-saving technology. Consequently, we expect more technology adoption when standards tighten.

This also seems to be happening. Figure 4 shows percent changes in power train efficiency for cars and light trucks since 2000. Efficiency is defined to include both fuel economy and horsepower changes, as well as other attributes related to fuel economy (such as weight). The vertical lines show the periods in which new standards were created for cars and light trucks. In both cases, after the standards tighten, the curve gets steeper, implying faster technology adoption and efficiency improvements. For example, efficiency of cars improved by about 1 percent per year before the standards tightened, and 2 percent per year after they tightened.

[7] See Klier and Linn (2016) and Leard et al. (2017).

Figure 4. Percent Changes in Power Train Efficiency for Cars and Light Trucks Since 2000



Source: Adapted from Klier and Linn (2016).

To summarize, tighter standards have increased the rate of technology adoption and caused consumers to forgo horsepower improvements. These changes imply costs, but just how large are those costs?

Under the new standards, which allow automakers to trade compliance credits, the credit price is proportional to the costs (i.e., the marginal costs) of the standards. For example, for an automaker selling emissions credits, the credit price is at least as high as the marginal cost of reducing emissions; otherwise, the automaker would be losing money by selling credits. A recent study by my RFF colleagues suggests that these credit prices have been modest; about $40 per metric ton of carbon dioxide, or (equivalently) about $100 per mile per gallon per vehicle.[8] I consider these costs to be modest because they're comparable to previous estimates of the social cost of carbon dioxide or the fines paid under the fuel economy standards for noncompliance. In other words, even though the standards thus far impose costs on automakers and consumers, the benefits appear to exceed the costs.

Plug-In and Information Technologies

Because of their dominance in the US market, I've focused on gasoline-powered technologies thus far in my testimony. Yet plug-in vehicle technologies are gaining market share and could potentially replace gasoline-powered vehicles in the long term.

[8] See Leard and McConnell (2017).

A range of policies incentivize consumers to buy or lease plug-ins. Some subsidies directly reduce the cost of obtaining these vehicles (such as federal and state tax credits for purchasing them). Other subsides are indirect, such as publicly funded infrastructure for recharging plug-in vehicles (which reduces refueling costs). Importantly, California's Zero Emission Vehicle Program mandates a certain level of plug-in sales in California and across several other states that have joined the program.

Presently, plug-in vehicle sales depend on subsidies. Since 2011, when plug-ins first entered the US market, their market share has grown to about 1 percent. Automakers are regularly introducing new plug-ins, such as the Tesla Model 3. Direct subsidies are typically at least $10,000 per vehicle, and indirect subsidies could easily add a further $10,000 per vehicle.[9] Nevertheless, most consumers currently choose other vehicles.

The experience with hybrid vehicles may be instructive about what happens with plug-ins. With hybrids, each successive version was better than the one it replaced. The same should hold true with plug-ins, as vehicles become easier to operate and more enjoyable to drive. Battery costs will continue falling, bringing the cost of producing a plug-in closer to the cost of producing an otherwise comparable gasoline-powered vehicle. However, as we've seen with hybrids, the transition from one vehicle technology to another tends to be gradual.

Plug-in innovation benefits automakers and consumers, as well as society. Consumers benefit from better technologies and expanding vehicle options; automakers benefit from higher profits and lower costs of meeting standards for fuel economy and greenhouse gas emissions. Where society is concerned, compared to gasoline-powered vehicles, plug-ins consume less gasoline and also reduce emissions (this will be true especially in the future, as electricity generation becomes cleaner).

New information technologies are transforming the way many people travel. Technologies that enable ride-sharing services, such as Uber, offer consumers new transportation options. Numerous cities have bike-share programs. In some cities, private companies compete with the main program (for example the brightly colored dockless bikes that were recently sprinkled

[9] See Jenn et al. (2016) and Linn and McConnell (2017).

across Washington, DC). Many consumers take advantage of these new options, reducing their travel costs, travel times, or both. The benefits to consumers are quite large, perhaps billions of dollars per year for Uber users alone.[10]

In thinking about the future, we should be careful about getting caught up in the hype about these technologies. About 10 years ago, after decades of steadily growing vehicle use, it appeared that vehicle use was leveling off and even decreasing. Many observers argued that differences in driving behavior were causing these changes (such as millennials who do not own a car or even have a driving license). But it turns out that this slowdown in driving growth was temporary, and caused mainly by economic factors, especially slowing income growth and employment (largely due to the 2008–2009 recession).[11] That is, it's true that millennials drive less, but other factors were more important. By analogy, ride-sharing services are clearly affecting travel for many people, but it's unclear whether they'll ultimately affect travel far outside urban areas.

Although these new information technologies benefit consumers, the technologies have uncertain effects on energy security and the environment. Standards for fuel economy and greenhouse gas emissions aim to reduce fuel consumption and emissions. They target fuel consumption rates (gallons of fuel per mile of travel) or emissions rates (grams of carbon dioxide per mile). Total fuel consumption and emissions depend on not just these rates, but also miles traveled; for example, total fuel consumption equals the average fuel consumption rate, multiplied by total miles traveled. Therefore, if information technologies increase total travel, they could increase total fuel consumption and emissions.

We should expect information technologies, particularly ride-sharing services, to increase miles traveled. Individuals who would have previously used public transportation or walked may now prefer using Uber, Lyft, or other services. This would imply a shift in travel behavior to ride-sharing and away from non-vehicle travel. There could also be an increase in total travel. Some individuals who might have stayed home may now use a rideshare because of the lower travel costs. Lower travel costs benefit consumers, as they can now enjoy cheaper and less time-consuming travel. But, from a societal perspective, total fuel consumption and greenhouse gas

[10] See Cohen et al. (2016).
[11] See Leard et al. (2016).

emissions may increase. A similar argument would apply to fully automated vehicles in the future.

Implications of New Technologies for Federal Policy

I'll discuss two implications of these technological innovations for federal policy. First, the tightening standards for vehicle fuel economy and greenhouse gas emissions have induced a lot of technology adoption for gasoline-powered vehicles, making them more efficient and less costly for consumers. The standards have probably induced some innovation as well—technologies that wouldn't exist if it weren't for the standards. Technology adoption and innovation are no accident, as they are exactly what we expect to occur under flexible regulations that set standards for automakers and allow them to figure out how to comply. The automobile industry has demonstrated quite a lot of ingenuity, and that's helped keep the costs of the standards at a modest level.

Second, fuel economy and greenhouse gas emissions standards could be adjusted to account for changes in travel behavior and vehicle utilization. State and local policies will continue to affect how information technologies influence total vehicle use (for example, policies that encourage carpooling). But federal vehicle fuel economy and greenhouse gas emissions standards also play an important role. Right now, an automaker's fuel economy and emissions requirements do not depend on how much its vehicles are driven; all cars are subject to one set of standards and all trucks are subject to another set of standards. For example, suppose an automaker sells two types of vehicles, the first of which is typically driven 100,000 miles over its lifetime, and the second of which is typically driven 200,000 miles. A given fuel economy improvement to the high-mileage vehicle saves twice as much fuel as would the same fuel economy improvement for the low-mileage vehicle. Consequently, the automaker should be rewarded twice as much under the standards for improving the fuel economy of the high-mileage vehicle. But in fact, the standards create the same incentive for the two types of vehicles.

This inefficiency has always existed with the standards. It implies that automakers do not have the right incentives for choosing fuel economy across the vehicles in their fleets. Changes in travel behavior caused by information technology could exacerbate this inefficiency. Federal standards could address it by crediting fuel economy improvements or greenhouse gas emissions reductions based on a vehicle's expected mileage.

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