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COMBINATIONS OF INSTRUMENTS TO ACHIEVE LOW-CARBON VEHICLE-MILES

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March 2010

The views expressed in this paper are those of the authors and do not necessarily represent positions of the University of Illinois, the OECD or the International Transport Forum.

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Champaign, March 2010

1. INTRODUCTION

Policymakers and economists have considered a number of different policies to reduce carbon emissions, including a carbon tax, a cap-and-trade permit system, a subsidy for the purchase or use of low-carbon vehicle technology, a renewable fuel standard, and mandates on manufacturers to increase the average fuel efficiency of the cars they sell. In this paper, we address issues in the use of these instruments separately or together. We consider the conditions under which policy makers should consider each such policy, and we show how the stringency of one such policy must depend upon the extent to which other such policies are already employed.

According to the theory of Pigou (1932), a simple tax or permit price per unit of emissions can minimize the total social cost of a given amount of emission abatement, because it would induce all individuals and firms to cut emissions in the cheapest ways, using any abatement method that costs less per unit of abatement than the tax that would have to be paid on the emissions. In general, this ideal Pigovian tax would have both substitution effects and output effects. For example, a tax on smokestack emissions would raise the price of pollution and encourage the firm to substitute into cleaner use of capital or other inputs instead. It would also raise the price that the firm would have to charge, to break even, and so customers would buy less of their output. In other words, less pollution per unit of output *and* less output.

For vehicle emissions, the driver is the polluter. A Pigovian tax on carbon emissions would raise the cost of driving large cars with low fuel efficiency, and so it would encourage drivers to substitute into low-carbon vehicles such as hybrids to reduce the emissions per unit distance (per mile or per kilometer). The carbon tax would still have to be paid on the fuel that does get used, however, so it would also encourage all drivers (even those with hybrids) to reduce distances driven. That is, the substitution effect reduces emissions per mile, and the "output effect" in this case is to reduce the number of miles driven.

In other words, if a tax or price of carbon is already in place, at the optimal rate, then that one policy by itself will encourage drivers to switch to low-carbon vehicles, to the optimal degree, with no need whatsoever for any additional policy to subsidize low-carbon vehicle technology. Indeed, an additional policy to encourage low-carbon vehicles would be not only "counterproductive" but would lead to excess social costs from too many such vehicles.

Unfortunately, however, a Pigovian tax is not always available. For some greenhouse gas emissions, it might be too expensive to measure the number of units from each source in order to apply the tax per unit. Also, political realities in some countries make the implementation of a new tax unlikely or impossible. In the U.S., many think the income tax is too high, and they fear that an additional tax would just make government larger. Politically, any new "tax" is a dirty word. Even the enactment of a cap-and-trade permit system is called "cap-and-tax." In addition, a carbon tax or permit price would raise the cost of electricity and gasoline and have regressive effects with disproportionate burdens on low income families that spend a high fraction of their income on these goods. If all of these reasons prevent the enactment of a carbon tax or price, then policymakers cannot achieve the "first best" cost-minimizing policy and can instead consider what policies might be "second best." Without a carbon tax or price, the second best might be achieved by a combination of policies that could include a subsidy to low-carbon vehicle technology, as well as other taxes, subsidies or mandates that help reduce carbon emissions in relatively cheap ways.

According to the United States Environmental Protection Agency (U.S. EPA), approximately 95 percent of direct greenhouse-gas emissions from vehicles are in the form of carbon dioxide and are proportional to the amount of gasoline or diesel fuel consumed. The remaining 5 percent of direct vehicle greenhouse-gases come from methane and nitrogen dioxide that form in proportion to the number of miles driven. In addition, hydrofluorocarbons (HFCs) leak from vehicle air-conditioning units.[1] Due to the high correlation between fuel usage and direct carbon emissions, and in the absence of an ideal Pigovian tax, a gasoline tax appears to be a reasonable second-best policy for reducing carbon emissions from vehicles. Yet political constraints also limit the effectiveness and feasibility of using a gasoline tax to combat climate change. First, politicians may find it expedient to provide tax exemptions for special interest groups. Second, even if a gasoline tax equally applies to all industries and sectors, the tax rate would likely be set below the marginal environmental damage from carbon. Third, many politicians, especially in the United States, will not vote for any policy that raises any tax rate.

In cases where the first-best carbon tax and a reasonable second-best gasoline tax are unavailable, this paper demonstrates how alternative combinations of instruments can form economically-sound, environmentally-motivated policies for substantial reductions in vehicle carbon emissions. In order to implement alternative approaches successfully, our point is that policymakers may need to take a holistic approach when designing policy. This holistic approach would recognize that policies to reduce carbon emissions must be politically feasible, and that all sectors of the economy generate carbon emissions. A holistic approach would not focus just on one method of abatement like encouraging low-carbon vehicle technologies, but instead on the efficient balance between all different abatement methods.

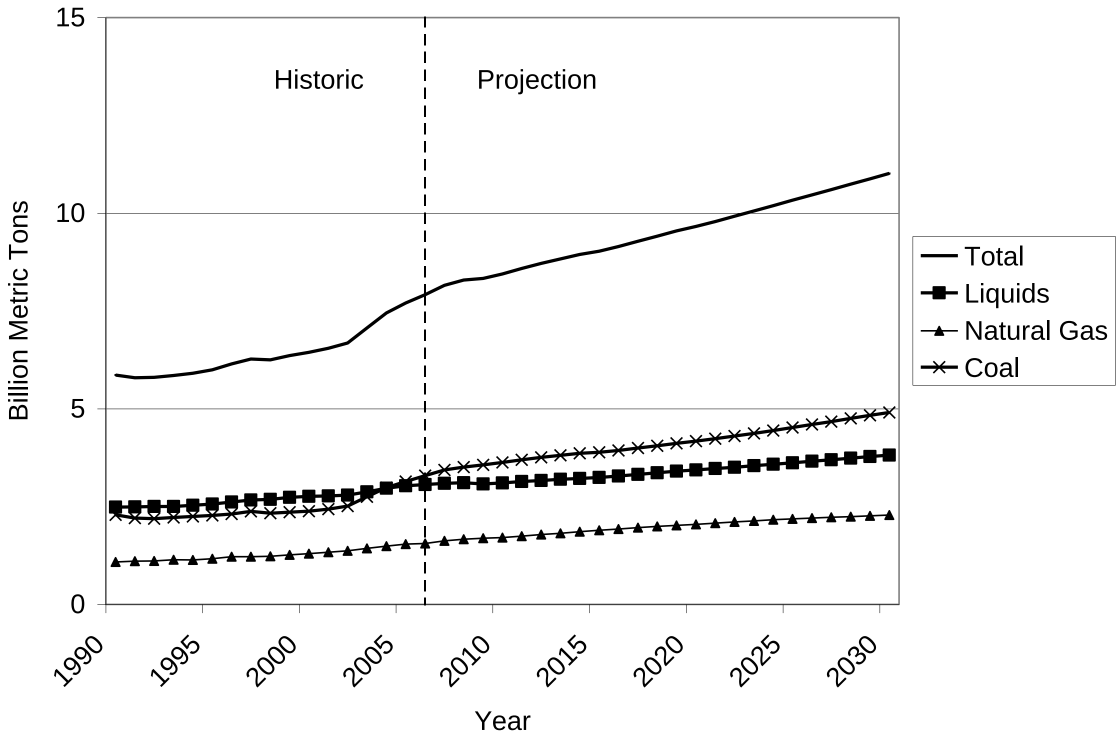
Combinations of carefully calibrated policy instruments can mimic the efficient outcomes of the first-best pollution tax [as discussed in Fullerton and West (2002, 2010)]. The fundamental idea is to consider how everyone – consumers and producers alike – would act in the event of a carbon tax, including their diverse uses of different abatement methods. Facing a carbon tax, some would buy a hybrid car, while others telecommute to work. Some would buy insulation for their homes, while others would move to a different house (perhaps with more insulation, or maybe close enough to walk to their place of employment). Then, absent a carbon tax, policy-makers could provide separate incentives or mandates for each of those same actions to be undertaken by each of those same individuals and corporations. That is, the instrument combination could be designed to induce the equivalent substitution effects and output effects of the ideal Pigovian tax. An incomplete list of alternative instruments includes: fuel efficiency standards, fleet hybrid quotas, subsidies for new vehicle purchases, subsidies to scrap old vehicles, and low-carbon fuel standards.

The first section below provides relevant descriptive statistics that inform our case for policies that mimic a carbon tax to achieve all of the same substitution effects and output effects. Next, we summarize some of the current policies in the United States and Europe that directly or indirectly limit carbon emissions from vehicles. In the subsequent sections, we briefly discuss externalities from vehicles, and the ideal cost-efficient tax on emissions; we expand on the idea of taking a holistic approach to reduce carbon emissions; and we lay out the additional policy objectives related to enforceability, political feasibility, leakage, heterogeneity, equity, and fiscal sustainability. Continuing, we provide three examples of how alternative instruments can mimic the effects of a carbon tax. Finally, we address four complicating issues (vehicle portfolio choice, uncertainty and learning, fleet dynamics, and infrastructure). These considerations would all enter a holistic approach to the implementation of multiple alternative policy instruments.

2. TOO MUCH POLLUTION, TOO MANY CARS, TOO MANY MILES

Carbon emissions from vehicles significantly contribute to global greenhouse-gas pollution that threatens the planet's ecology and economy. The most recent International Energy Outlook (IEO) calculates that burning liquid fuels in 2006 contributed 38.7 percent of the 8 billion metric tons of the world-wide, energy-related carbon emissions. (Gasoline and diesel fuel used in ground-level vehicles constitute major components of the liquid fuel category.) Figure 1 charts global historic and projected energy-related carbon emission by fuel type from 1990-2030 as estimated by the IEO. Liquid fuel constituted the highest share of energy-related carbon emissions until 2004, when coal became the largest single emitter by fuel type. While stationary sources (e.g. power plants) burn much of the world's coal, the consumption of liquid fuels mainly occurs in mobile sources (e.g. vehicles), creating a different set of regulatory challenges for policymakers. Therefore, the importance of considering policies to promote low-carbon vehicles is not diminished by the fact that coal now forms the largest share of world-wide, energy-related carbon emissions.

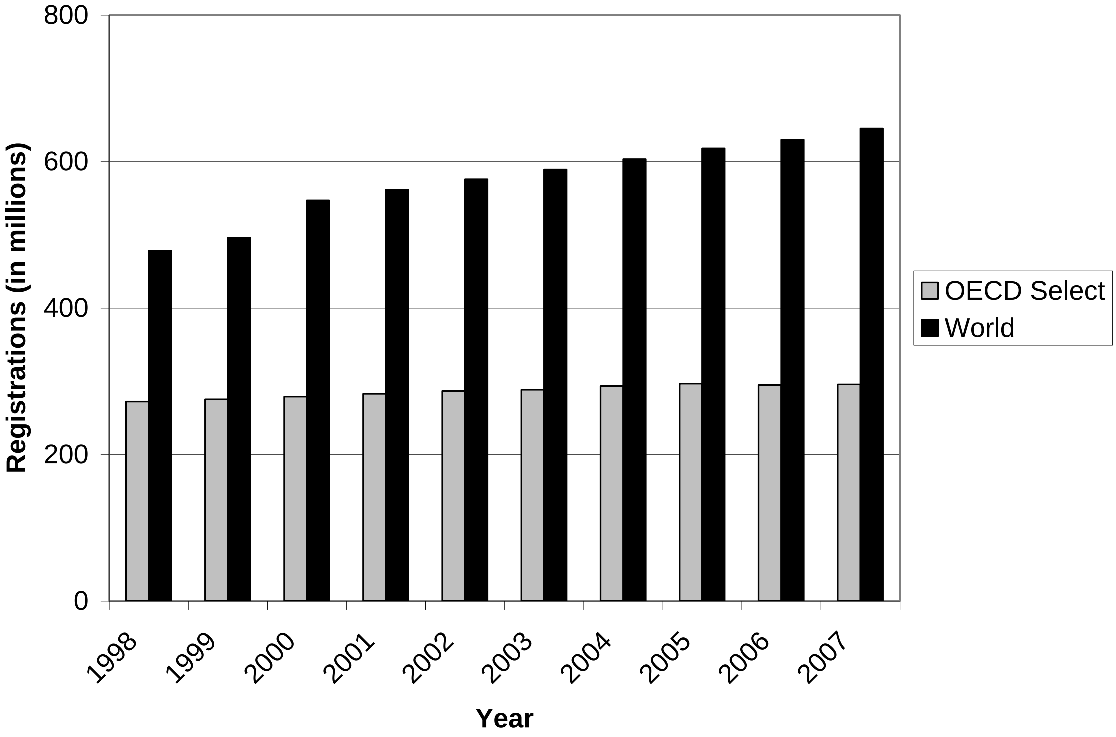
Figure 1. **Annual World Energy-Related Carbon Emissions by Fuel Type, 1990-2030**



Source: International Energy Outlook 2009 – Figure 81 (converted to carbon); DOE/EIA-0494(2009).

The projected increase in liquid fuel consumption is not unexpected, as the number of world-wide vehicles continues to grow. Using data from the latest Transportation Energy Data Book (TEDB), Figure 2 graphs world-wide car registrations from 1998-2007, showing that the 600 million car level was surpassed in 2004. By 2007, global car registrations increased by 34.8 percent compared to the 1998 level, while the United Nations estimates that world population only increased by 5.7 percent over that same time period. Yet the staggering number of cars registrations reported by the TEDB significantly underestimates the total number of vehicles for two reasons. First, these data do not count trucks or 2-wheeled vehicles. Second, official statistics cannot account for illegally operated vehicles. In short, the total number of vehicles on Earth is likely increasing faster than population growth. In addition, Figure 2 graphs car registrations from 1998-2007 for a subset of OECD countries (France, Germany, Japan, United Kingdom, and the United States). In 1998, these five countries had 56.9 percent of the world's cars, but exhibited just 8.6 percent growth over the period. By 2007, they accounted for just 45.8 percent of global car registrations, a drop of more than 10 percentage points in a decade.

Figure 2. **Car Registrations for Some OECD Countries and the World, 1998-2007**

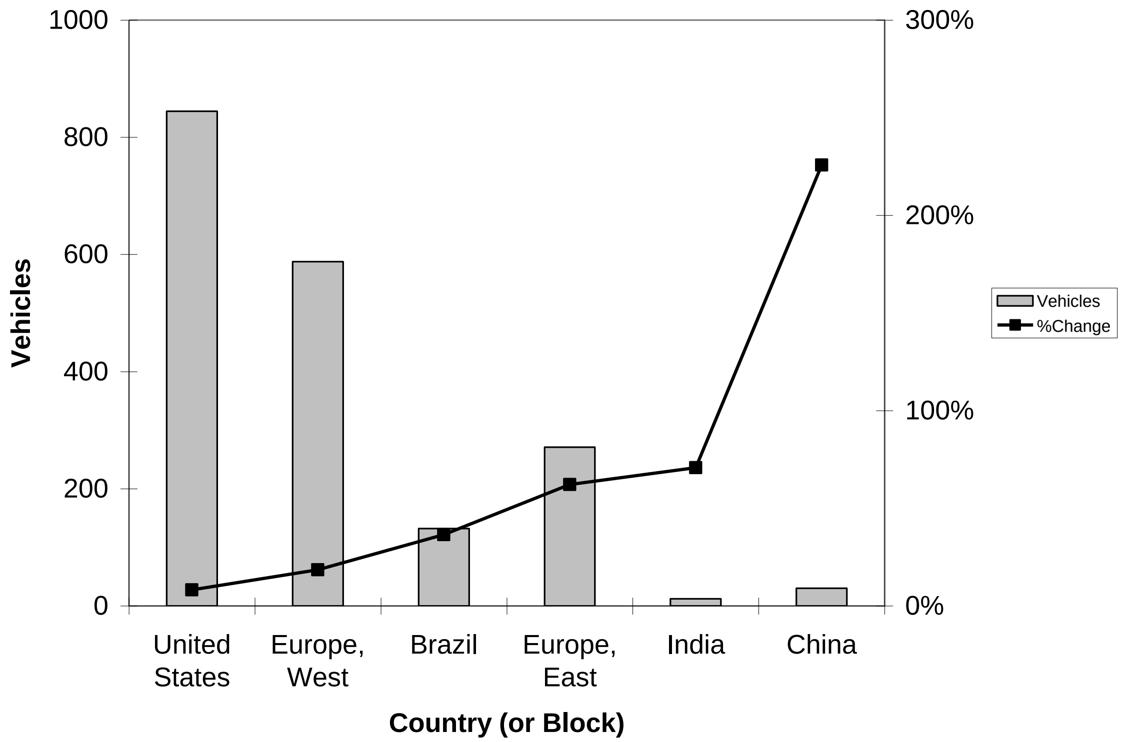


Source: Transportation Energy Data Book (TEDB), Edition 28-2009, Table 3.1.

Disclaimer: Our "OECD subset" includes all OECD countries for which we have TEDB data, thought this definition in no way reflects the opinion or structure of the OECD. Our OECD subset includes France, Germany, Japan, United Kingdom, and the United States.

On a per capita basis, vehicle registrations and growth rates vary widely across countries. As calculated by the TEDB, the bars in Figure 3 shows for select countries the *number* of vehicle registrations per thousand people (measured relative to the left-side vertical axis). Then the line in the figure shows the *change* in the number of vehicle registrations per thousand people (measured relative to the right-side vertical axis). The United States has a relatively high vehicle saturation rate, with 844.4 vehicles per thousand people in 2007, an 8.2 percent increase from the 1996 level. Countries in Western Europe have similarly high vehicle saturation rates and low growth rates. In contrast, China has only 30.3 vehicles per thousand people in 2007 due to its large population, but even that low level constitutes a 225 percent increase over the 1996 level. India reports a similar profile as China. Interestingly, Eastern Europe and Brazil have medium vehicle saturation rates and medium growth rates. It is not surprising that the growth in the per capita vehicle rate slows as the number of vehicles approaches parity with the population; given the large populations of China and India, however, the potential remains for a very large number of vehicles to begin operating in those countries.

Figure 3. **Vehicle Registrations per 1000 People for Selected Countries (or Blocks) in 2007, and the Percent Change from 1996 Level**



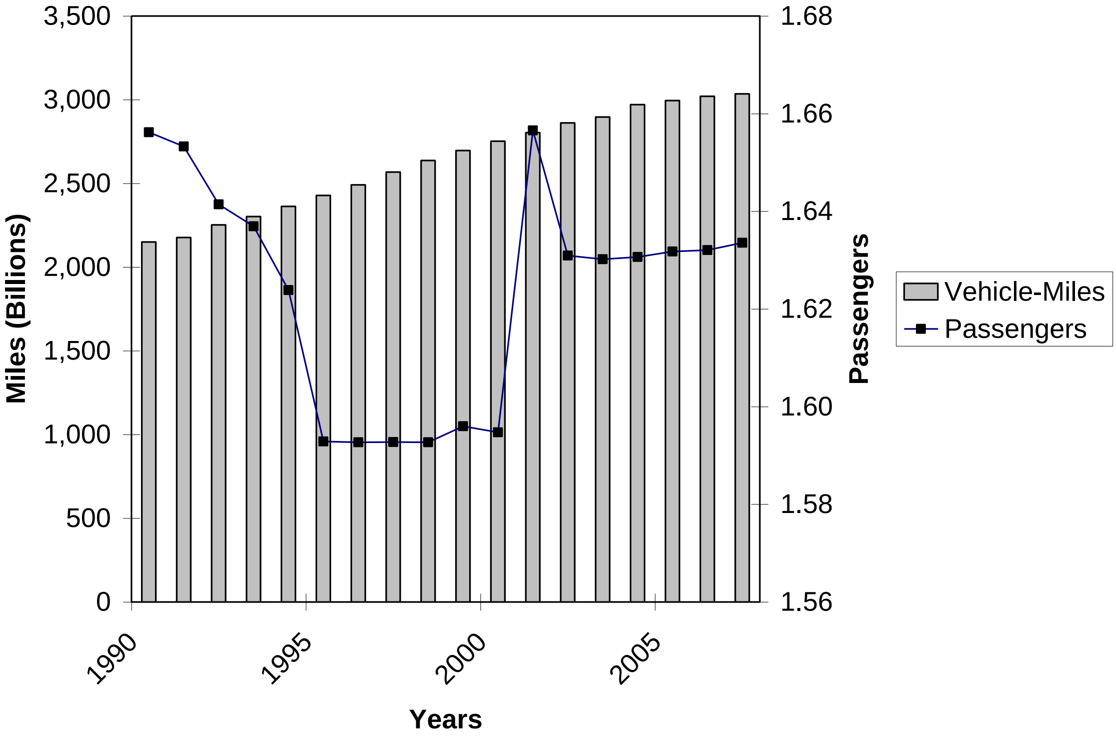
Source: Transportation Energy Data Book (TEDB), Edition 28-2009, Tables 3.4 & 3.5.

Disclaimer: The Blocks definitions used by the TEDB in no way reflect the opinion or structure of the OECD.

Block definitions: Europe, West: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom; and, Europe, East: Belarus, Bulgaria, Croatia, Czech Republic, Hungary, Montenegro, Poland, Romania, Russia, Serbia, Slovakia, Slovenia, and Ukraine.

The latest statistics from the U.S. Department of Transportation provides evidence that the ever growing fleet of vehicles are being driven greater distances. For instance, in 2006 residents of the United States travelled 16,418 highway passenger-miles per capita, a 15.3 percent increase over the 1990 level; that is, during this single year, the average American travelled in vehicles for a distance equivalent to two-thirds of the Earth’s circumference. However, multiple passengers often occupy the same vehicle, and so the total vehicle-miles driven are fewer than the total passenger-miles travelled. While adding passengers marginally increases the fuel consumption of a vehicle, a large share of vehicle emissions occurs regardless of the number of passengers. The bars in Figure 4 shows the gradually increasing number of total U.S. highway vehicle-miles (measured relative to the left-hand vertical axis). From 1990-2007, total highway vehicles-miles increased 41.2 percent to over 3 trillion miles per year; meanwhile, the population of the United States increased only 20.8 percent over the same period. The line in the figure shows the average passenger occupancy rate, APOR (relative to the right-hand vertical axis). The APOR falls and remains low through the 1990s, but appears to jump in 2001 and subsequently stays above 1.62 passengers per vehicle.[2] Multiplying vehicles-miles (the bars) times the APOR (line) yields total passenger-miles in each year.

Figure 4. **United States Highway Vehicle-Miles & Average Passenger Occupancy Rates, 1990-2007**

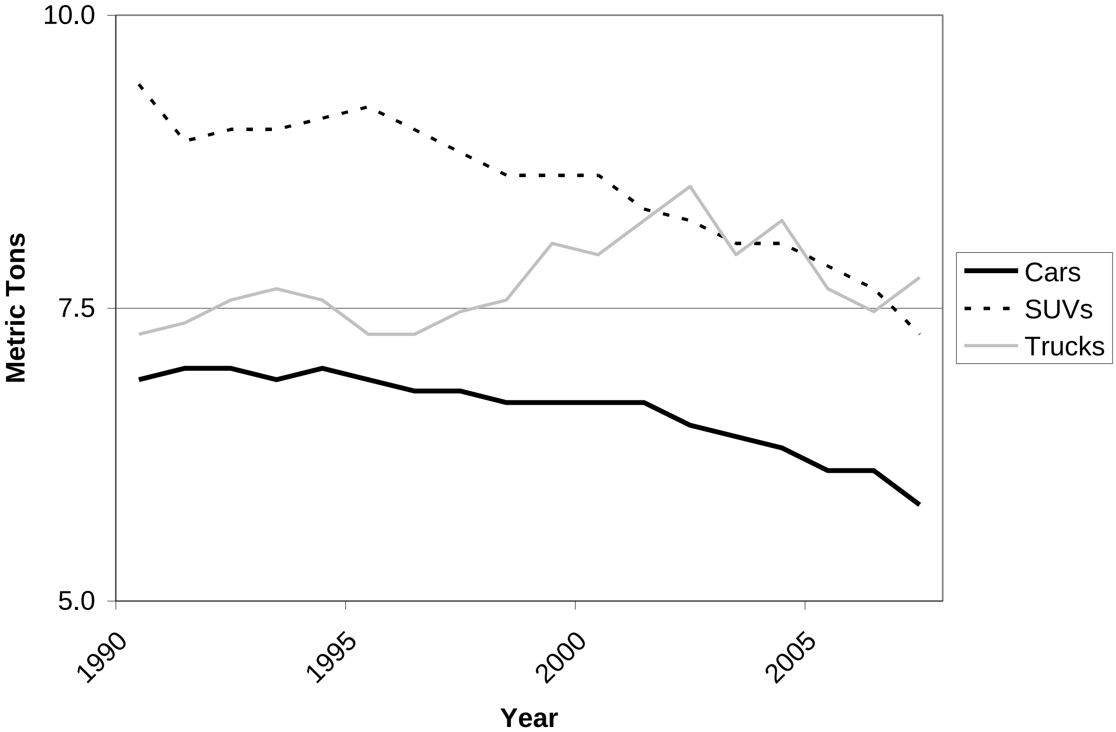


Source: U.S. Bureau of Transportation Statistics, National Transportation Statistics (NTS), Table 1-32 & Table 1-37.

Methodology: To derive the Average Passenger Occupancy Rate, we divide total U.S. highway passenger-miles by total U.S highway vehicle-miles. According to NTS Table 1-37, "Passenger-miles for passenger car, motorcycle, and other 2-axle 4-tire vehicles were derived by multiplying vehicle-miles for these vehicles by average vehicle occupancy rates, provided by the Nationwide Personal Transportation Survey (1977, 1983, and 1995) and the National Household Travel Survey (2001)."

Despite the 41.2 percent increase in vehicle-miles, total emissions from vehicles still might have fallen over that period 1990-2007, if vehicles greatly reduced their emissions per mile. Figure 5 charts the sales-weighted annual carbon footprint of new, medium-sized U.S. domestic and import cars, sport utility vehicles (SUVs), and pickup trucks from 1990-2007. (The annual carbon footprint assumes 15,000 miles, with 55% city driving and 45% highway driving, and it includes greenhouse-gas emissions from carbon dioxide, methane, and nitrogen dioxide.) Both cars and SUVs exhibited declines in their annual carbon footprint – by 15.5 and 22.7 percent, respectively – while trucks showed a slight increase of 6.7 percent over the period. In the end, the decreased carbon footprint of some new vehicles did not offset the large increase in vehicles-miles for the entire fleet. As a consequence, the U.S. EPA's 2009 Greenhouse Gas Inventory reports that carbon emissions from cars, SUVs, and trucks indeed increased 34.0 percent from 1990-2007.

Figure 5. **United States Sales-Weighted Annual Carbon Footprint of Medium-Sized, New Domestic and New Import Cars, SUVs, and Trucks, 1990-2007**



Source: Transportation Energy Data Book, Edition 28-2009, Tables 11.8 and 11.9

3. CURRENT POLICIES IN THE UNITED STATES AND EUROPE

Many countries have direct or indirect polices to address the problem of carbon emissions from vehicles. This section provides a brief overview of some of these policies in the United States and Europe.

The United States does not have federal greenhouse-gas (GHG) emission regulation for vehicles or stationary sources. Indeed, it was not until April 2009 that the U.S. government officially recognized greenhouse-gases as a threat to public health through the effects of climate change. However, many other federal policies may indirectly limit carbon emission from vehicles, and we highlight two examples: the Corporate Average Fuel Economy (CAFE) program and the Renewable Fuel Standard (RFS).

In 1975, Congress enacted CAFE in response to the 1973-74 Arab oil embargoes. As the U.S. National Highway Traffic Safety Administration explains, CAFE sets a 25 miles per gallon (mpg) minimum target for the "sales-weighted average fuel-economy… of a manufacturer's fleet of passenger cars or light trucks with a gross vehicle weight rating (GVWR) of 8,500 lbs., or less, manufactured for sale in the United States, for any given model year." As a co-benefit to reducing oil usage, CAFE likely reduces direct emissions from vehicles under the GVWR limit. The additional environmental benefit is mitigated by two factors. First, popular large trucks and large sport utility vehicles have not all been subject to the CAFE program.[3] Second, if CAFE increases vehicle mpg, then it reduces the cost per mile driven and may therefore encourage more driving. This "rebound" effect is discussed in much literature, as summarized in Parry et al (2007).

One other point about the CAFE standards is relevant to the comparison of regulatory mandates and other incentive-based policies like a tax or subsidy. Any given auto manufacturer can use two basic methods to help satisfy this mandate regarding their corporate average fuel economy (the sales-weighted average of the vehicles sold that year). First, they can adjust the technology of their cars sold, to increase the fuel efficiency of any given car. Second, given the chosen technology, they can try to increase the number of small fuel-efficient car sales relative to large car sales. Thus the car company has some incentive to cross-subsidize, charging a little more for large cars in order to cut the price of small cars. In doing so, each car company can still break even, in competitive equilibrium. In other words, this mandate probably leads to an equilibrium pricing *outcome* that looks a lot like a public policy incentive program to tax large car purchases and use that tax revenue to subsidize small fuel-efficient car sales.

Next, the Renewable Fuel Standard (RFS) program authorized by the Energy Policy Act of 2005 mandates renewable fuel blending into gasoline. The RFS mandate specifically requires 36 billion gallons of renewable fuels blended into gasoline per year by 2022, an increase of 350 percent over the 2008 level. These renewable fuels consist of corn ethanol, biomass-diesel, and advanced cellulosic ethanol. Carbon dioxide may be emitted during combustion of these feedstocks, but it is recycled through absorption during the growth of the feedstocks. Still, concerns have been raised about the lifecycle carbon impact from increased land usage to grow feedstock, nitrogen-based fertilizer application, and energy use in the conversion process (Holland, Hughes, and Knittel, 2009).

In addition to federal policies, individual states, and groups of states, have substantial power to enact their own environmental policies. For example, individual states have gasoline taxes (which average to a rate similar to the federal rate of tax per gallon).[4] Also, ten Northeast and Mid-Atlantic states form the Regional Greenhouse Gas Initiative (RGGI), which limits carbon emissions from the power sector using a cap-and-trade program. With regards to vehicle emissions, California has been particularly aggressive in promulgating rules and regulations. Specifically, California regulators fought for and recently obtained a waiver from the U.S. EPA that allows an increase in that State's vehicle efficiency standard beyond the CAFE standard.

Unlike the United States, Europe has far reaching and direct carbon policies. Phase II of the European Union Emission Trading System (EU-ETS) currently limits carbon emissions from a range of sources and industries using a cap-and-trade program. However, the EU-ETS does not currently apply to the transportation sector, as gasoline and diesel are already subject to high tax rates in most countries. A problem is that the existing fuel tax rates do not necessarily reflect the marginal environmental damage from carbon, because they were set to meet other objectives.[5] Still, high fuel taxes in Europe may already be inducing shifts toward fuel-efficient vehicles.

4. BENEFITS, COSTS, AND EXTERNALITIES

The externality from vehicle pollution fundamentally occurs because individual drivers do not take into account the full social cost of their actions, where those social costs include not only the individual's private cost but also the monetary value of all negative impacts on others. This section discusses those private and external costs, focusing on climate change. The bottom line is that an individual who weighs the private costs and benefits of driving will generate more carbon emissions than is socially optimal.

Individuals privately benefit from driving in many ways. If these benefits can easily be met using low-carbon alternatives, then it will be easier to reduce carbon emissions. We identify three categories of driving benefits. First, driving is a substitute for other forms of transportation; individuals are more likely to drive private vehicles when they do not have viable low-carbon alternatives like some public transit, walking, and bicycling. Second, driving is a complement to particular goods and services. If an individual must be in a specific location to consume a good or use a particular service, then driving is a complement to that good or service. For instance, driving might be considered a complement to leisure. Finally, driving has intrinsic joys. One can imagine these intrinsic joys deriving from a desire to drive faster or travel farther than can be achieved by human locomotion.

Conversely, the private costs of operating a vehicle including the purchase or rental price, repairs and maintenance, fuel costs, insurance premiums, and the time spent driving.

Beyond the private benefits and costs, drivers produce negative externalities that may include: local ambient air pollution, congestion, and increased risk of accident, as well as the global externality of climate change from carbon emissions. While the scientific community has consensus about the human causes of climate change, the economic community does not have consensus about the monetary costs of these damages. Estimates of the marginal environmental damage vary widely from $20 to $300 per short ton of carbon, which translates into a range of 5 to 72 U.S. cents per gallon of gasoline (or about 0.14 to 2.0 € per litre).[6] Among other reasons, differences in social discount rates lead to the wide range of monetary damage estimates.

While this paper focuses on carbon emissions, vehicles and driving produce other negative externalities (as surveyed by Parry, et al 2007). Traffic congestion on roads is perhaps the most salient negative externality from driving, and London has famously introduced a congestion fee for vehicles entering the city center. The technology may now be available to use each car's global positioning system (GPS) to record exactly when and where that car is driven, in order to send a bill at the end of the month.[7] Then the fee for driving could be higher on particular roads when they are more crowded. In addition, each additional mile driven raises somebody else's chance of an accident. Driving also causes air and water pollution. Vehicles commonly leak fuel, fluids, and lubricants that eventually flow into streams, lakes, and oceans. On top of carbon emissions that cause global warming, vehicles also cause significant negative health consequences for children and adults from emissions of many criteria pollutants (particulate matter, ground-level ozone, carbon monoxide, sulfur oxides, and lead).

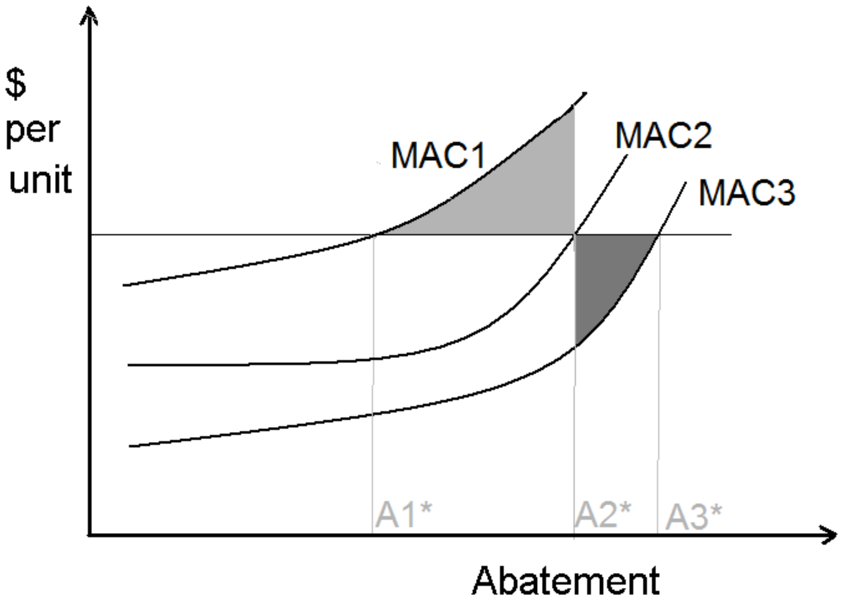
5. THE 'IDEAL' TAX ON EMISSIONS

According to the theory of Pigou (1932), damages from an externality such as pollution can best be mitigated by imposing a tax (or permit price) per ton of emissions from any source. If the problem is global warming from carbon dioxide emissions, this theory suggests imposing a tax per ton of carbon dioxide emissions. This price per ton then can encourage any emitter to undertake the cheapest forms of abatement – using any technology that reduces a ton of emissions in a way that costs less than the tax. Such a policy is economically efficient, because it minimizes the total cost of any given amount of abatement.

To abate carbon dioxide emissions from vehicles, one can: get a tune-up; fix broken pollution control equipment; retire and scrap an old vehicle with low fuel efficiency; buy a newer car with any number of features that increase fuel efficiency; change driving style to avoid aggressive driving; and avoid cold start-ups. These choices are all abatement options, because they reduce CO_2 emissions for a given number of miles driven. In addition, one can reduce miles driven: ride a bike, take mass transit, telecommute one day per week, move to a home closer to work, or change jobs to work closer to home. Each of these many abatement methods has a different, rising marginal abatement cost (MAC). Figure 6 shows just three MAC curves, where the horizontal axis measures abatement and the vertical axis measures per unit cost of abatement.

For example, suppose MAC1 represents the cost of achieving additional carbon dioxide abatement by getting people to use mass transit; this curve may rise because initial rail users can easily walk to the train station from houses nearby, while additional riders must get to the stations from further away. Suppose MAC2 is the cost (per ton of carbon dioxide abatement) from additional telecommuting; one day per week is no problem, but the second day comes at higher cost. Equivalently, some workers can telecommute easily, while others do so at increasing marginal cost. And suppose MAC3 is the cost of achieving additional abatement by making cars lighter to get better fuel efficiency and cut gasoline use per mile. This curve rises because some components can easily be made from lighter materials, while other components are less suited to be made from lighter materials.

Figure 6. **Stylized Marginal Abatement Cost (MAC) Curves**



Next suppose that a tax per unit of carbon emissions is imposed, with the rate equal to the height of the horizontal, grey line in the figure (ideally, this Pigovian tax would equal the marginal environmental damage from carbon). Then commuters would face higher costs of driving, and they would sort themselves efficiently. In this figure, A1* of abatement would be achieved when some commuters walk to the train station at low cost, while other commuters find that difficult and still drive. Also, A2* of abatement is achieved when some workers telecommute, while others need to be at the office and still drive. And A3* of abatement is achieved when people buy cars that are lighter and more fuel efficient – but expensive methods to achieve fuel efficiency are not undertaken.

The key is that this combination minimizes the cost of that total emission abatement. If the government were to mandate or subsidize enough mass transit so that method 1 was used to achieve as much abatement as method 2, then the extra cost to society would be the light grey area (the extent to which those abatement costs are higher than necessary). Conversely, if the government were to mandate or induce too little fuel efficiency, so that method 3 were to achieve only as much abatement as method 2, then the net loss to society would be the dark grey area (the foregone cost savings from not using that cheaper form of abatement).

The same theory applies more generally, with any number of abatement methods. If all sources in all sectors face the same price per ton of emissions, then each has incentive to use any method to abate carbon dioxide emissions that is cheaper than paying the tax per unit of carbon dioxide emissions.

Thus, a carbon tax by itself will induce all methods of abatement to the efficient, cost-minimizing degree. Yet, if a carbon tax is unavailable, then a carefully planned policy can use combinations of instruments to mimic the carbon tax, but only if each of the abatement behaviors is induced to the efficient level. In the example above, the government would need to encourage mass transit ridership to the right degree for those particular additional riders. It would need to encourage or require telecommuting to the right degree, but only for the right workers. And it would need to encourage or mandate lighter cars, but to the right degree for the right cars.

To achieve perfect efficiency using all these multiple policies is unlikely, but efficiency does not need to be "perfect". If policy induces almost the right number of rail commuters, then the light grey shaded area in Figure 6 may be small; if government requires almost the right increase in vehicle fuel efficiency, then the dark shaded area may be small. In other words, it may be possible to achieve a fairly efficient combination of abatement methods through the artful combination of policies such as a CAFE standard, a subsidy to hybrid vehicles, a low-carbon fuel standard, an attractive price on mass transit, and a subsidy for the home use of internet for telecommuting.[8]

Yet this alternative combination of policies has a major drawback. To achieve economic efficiency using just the carbon tax, authorities do not need to estimate the MAC curves. They just set the tax rate and let individuals decide for themselves whether and where to drive. To enact a set of policies that would mimic that carbon tax, however, the information requirements are enormous. The authorities would need to estimate each MAC curve to be able to determine the optimal or nearly optimal amount of that abatement method. That information is costly to acquire, and it is estimated with error, so the outcomes may well be inefficient. Studies show that incorrectly implemented mandates can incur costs many times greater to achieve the same level of abatement as the efficient tax (e.g. Newell and Stavins, 2003).

6. HOLISTIC APPROACH

We were asked to write a paper about policies to encourage the adoption of low-carbon vehicle technologies, and certainly a good research effort could focus on this narrow question. Yet we find it difficult to think about what policies could *optimally* encourage the adoption of low-carbon vehicle technologies, because the answer to that question depends on what policies are already in place to affect other driving choices. Indeed, if drivers already faced the ideal Pigovian tax on carbon emissions, then that policy would already induce the optimal choices of vehicle, and any additional policy to encourage low-carbon vehicle technology would be counter-productive – and efficiency reducing. But if the carbon tax is zero and the gasoline tax is "too low", then households may not be willing to pay extra to buy hybrids or at least cars that are lower weight with more miles per gallon. In this case, the second-best optimal policy might well include subsidies to low-carbon vehicles. Thus the optimal second-best subsidy logically depends on the existing carbon tax or gasoline tax.

Moreover, that second-best optimization problem also depends on what policies can be implemented politically, what emissions can be cheaply monitored, and what regulations can be adequately enforced. Therefore, we suggest a holistic approach to reducing carbon from vehicles. This holistic approach would take into account multiple fundamental aspects of the climate change crisis. In this section, we discuss a few of these other considerations.

6.1. Enforceability

An enforceable environmental incentive policy often requires piggy-backing on transactions with receipts in order to eliminate tax evasion and subsidy scams. Even without taxes or subsidies, the accurate measurement of abatement actions is still required to enforce quotas or mandates. These considerations makes it very difficult or impossible to use market-based incentives for most conventional pollutants from vehicles, because a price per unit of those emissions would require a device to measure the actual emissions from each tailpipe, for hundreds of millions of cars. Those emissions are not a "market transaction" with an invoice to help administer the tax.

It would also be difficult to measure the carbon dioxide emissions from each tailpipe, but this problem is mitigated by the very high correlation between fuel consumption and direct vehicle CO_2 emissions. A carbon tax can be imposed on the carbon content of the gasoline or other fossil fuel, at the time of purchase, using an invoice to help administer the tax. Alternatively, global positioning technology can easily and cheaply track miles driven, but potentially flawed testing procedures or averages might then be used to assign emission rates for each vehicle.

Enforceability matters for the holistic approach: if the ideal Pigovian emissions tax cannot be administered and enforced, then the second best policy might be a combination of instruments to encourage nearly the right amount of each separate abatement activity.

6.2. Political Feasibility

Another important aspect of the holistic approach is to consider political feasibility. A direct tax on carbon emissions may be economically efficient, but political realities and special interest lobbying often prevent ideal polices from being enacted. In the United States, it appears unlikely that any Congress in the foreseeable future will pass a comprehensive carbon tax or cap-and-trade program. Instead, the U.S. Congress seems to prefer to set mandates and to provide subsidies.

Even in the European Union, with its "ideal" carbon pricing through the Emissions Trading System, political feasibility at the time of enactment allowed the EU Parliament to apply the EU-ETS only to about half of total carbon emissions (the "trading sector" includes electricity generation and certain major industries, but it excludes other industries, residences, and all of transportation). Using Figure 6, we could say that MAC1 represents the marginal cost of abatement in the trading sector, MAC2 is abatement in the residential sector, and MAC3 is abatement in the transportation sector. Even if abatement within the trading sector is efficient, inadequate abatement in the other sectors still means inefficiency, because cheap forms of abatement in other sectors are not being undertaken. In this case, the EU might need a "combination" of instruments to improve efficiency, such as permits in the trading sector and a carbon tax in the non-trading sector.

A goal of this paper is to show that a proper mix of alternative policy instruments can be used in combination to mimic direct and comprehensive carbon policy. Each nation may face different political constraints, to different degrees across a variety of different policy instruments. We therefore mean to provide a menu of policy approaches, from which policymakers can choose the workable combination for their own circumstances, in a way that depends on what is available. Even if a carbon tax is available, it may be too low, and other policies might be needed to supplement it. If a carbon tax is not available, then a normal gasoline tax might be very useful, to encourage less driving, while other policies for low-carbon vehicle adoption can help reduce the emissions per mile (kilometer).

At the present time, the accumulation of carbon emissions continues relatively unabated, so waiting for the right political conditions to enact the perfect piece of legislation could lead to actual outcomes much worse than using other available policy options.

6.3. Leakage

Greenhouse-gas emissions from any source and from any sector contribute equally to climate change. Furthermore, carbon dioxide and the other greenhouse-gases are stock pollutants that accumulate in the atmosphere, so emissions today have approximately the same climatic effects as emissions a decade from now. Two kinds of problems may arise from focusing too much attention on any one source of carbon emissions in a particular time period.

First, it can lead to emission leakage into other countries, or similarly into other sources, sectors, and years. That is, any targeted attempt to reduce vehicle emissions can lead to offsetting effects if households do something else instead that creates carbon emissions. Instead of driving, they may stay at home and burn natural gas in their furnace, and they may turn on the lights, the television, or other household appliances that run on electricity. And this electricity may be generated using fossil fuels such as coal or natural gas. Or, the policy may be designed to reduce vehicle emissions by encouraging households to buy zero-emission electric vehicles. For example, suppose a mandate requires 10 percent of each manufacturer's sales of new vehicles to be all-electric vehicles. The batteries used to power these motors will be recharged using electricity from the power grid, however, and this electricity may also be generated by the burning of fossil fuels. In order to mitigate the leakage from the all-electric vehicle mandate, a complementary policy instrument would need to limit carbon emissions in the electricity sector, such as a renewable portfolio standard that mandates the generation of renewable electricity. In general, leakage can be mitigated only by comprehensive policies that affect all burning of fossil fuel – not just petrol in vehicles.

Second, even without leakage, a targeted attempt to reduce vehicle emissions cannot be the most efficient way to reduce a given amount carbon emissions. It may require proceeding up the rising marginal cost curve for that particular form of abatement, while ignoring some other cheaper way to abate the same quantity of emissions from some other source.

6.4. Heterogeneity

Firms differ from each other in terms of size, available technology, and cost of abatement. Thus, they should not all be required to abate the same amount. Individuals differ from each other in terms of wealth, income, demographic characteristics, and preferences. As a result, the economically efficient policy generally will not require the same amount of abatement from each, nor even the same types of abatement. Facing a uniform carbon tax on all carbon emissions, some individuals will take the train, others will bicycle, some will buy a smaller car, and others will buy a hybrid. Some may not abate at all, choosing instead to pay the tax. The outcome is efficient, since each only abates by the methods and to the extent cheapest for them.

This idea is important for the design of a combination of multiple instruments intended to mimic the "ideal but unavailable Pigovian tax on emissions". Such a combination might well involve getting some people to buy hybrids or other low-carbon vehicle technologies, but a mandate that everybody must buy a new low-carbon vehicle technology may be an extremely expensive way to achieve any given amount of abatement. The little old lady who drives only once a week to the grocery store only one kilometer away should not be made to spend an extra $20,000 to buy a hybrid. Efficiency requires that she should buy the old fuel-inefficient large car from someone else who drives more distance (while that other person buys the new hybrid).

These considerations suggest the use of incentive policies in general, rather than mandates. A simple subsidy can encourage some to purchase a hybrid vehicle, while others do not. Note that even a mandate on each manufacturer's sales of vehicles can work like incentives to customers, like the CAFE standard described above. Similarly, if each manufacturer is required to sell electric vehicles as 10% of all new vehicle sales, then that policy is officially a "mandate", but it still allows some individuals to buy electric vehicles while others do not.

If a mandate or other policy requires the same amount or types of abatement from everyone, the result is an inefficient allocation of abatement. For example, Fullerton and West (2010) study non-carbon emissions from cars (volatile organic compounds, nitrogen oxides, and carbon monoxide). If all individuals were identical, then the first-best welfare gain of an ideal Pigovian tax can be achieved in their model by a uniform tax on gasoline, a tax on engine size, and a subsidy to "newness" of the vehicle.[9] But using the heterogeneous individuals in their data, they calculate that 71 percent of that maximum welfare gain can be obtained by imposing those uniform tax rates. The efficiency loss increases with the degree of individual heterogeneity.

6.5. Equity

These differences between individuals also potentially lead to unequal burdens. In general, polices designed to reduce carbon emissions can be regressive, for any of six major reasons outlined in Fullerton (2009). For instance, low-income individuals, on average, spend a disproportionate amount of their income on carbon-intensive goods and services like electricity and gasoline, so a policy that raises prices on these carbon-intensive goods and services hurts low-income individuals to a greater degree. However, rebates to low-income individuals can significantly reduce the regressive nature of carbon policies (Bento et al., 2009). Regarding vehicles, environmental policy that raises the cost of driving may not be regressive across the lowest income groups, because those with the least income may not own vehicles at all, as a result of high fixed costs and credit constraints. Instead, individuals in the middle of the income distribution disproportionately bear the burden of policies that raise the cost of vehicle travel. These middle-income individuals are wealthy enough to own vehicles, but not wealthy enough to ignore an increase in the variable cost of operating those vehicles. On the margin, some middle-income individuals may forego vehicle ownership. However, a fundamental tension remains between the policy objectives of efficiency and equity, due to imperfect information about individual abilities and limitations on the ability of government to make lump-sum transfers.

In our holistic approach, we argue for a combination of multiple policies to improve economic efficiency. Here, we note that a combination of multiple policies can help with equity as well. In addition to a carbon tax, policymakers might also want to provide some aid to low income families as a part of the policy reform package. And if a carbon tax is not available, then alternative policies in the package might be designed not just for economic efficiency, but also for equity. The package might include subsidies to low-income families to buy low-carbon vehicles, even if it does not subsidize high-income families to buy low-carbon vehicles.

6.6. Fiscal Sustainability

Economists recognize that the revenue generated by a carbon tax, or a cap-and-trade program that auctions permits, can be used for other welfare improving purposes like cutting income tax rates or paying down national debts (e.g. Fullerton and Karney, 2009). Unfortunately, political constraints limit the feasibility of environmental policies that raise revenue. Instead, if a policy plans to employ subsidies as a means of inducing carbon abatement, the large size of the transportation sector will require a non-trivial portion of fiscal expenditures to support the subsidy programs. Due to concerns about large national debts in many countries, environmental policies that are not fiscally sustainable may be cut in the future under budgetary pressure. In the long-run, government budgets must balance. Since carbon emissions have approximately the same negative effect on the climate regardless of when they are released, removing a subsidy later would offset the benefit of previous abatement.

Furthermore, if a government promises unrealistically large subsidies for future abatement activity, then economically rational agents might not undertake necessary investments to enable that abatement, fearing the subsidy will be cut in the future. Wind power in the United States provides a case in point. Beginning in the year 1992, wind generation during the first ten years of a wind farm's operation became eligible for 2.1 cents per kilowatt-hour production tax credit (PTC). Some members of Congress viewed the PTC as a needless and expensive subsidy, however, so the PTC was allowed to lapse in 1999, 2001, and 2003. In each of the subsequent years – 2000, 2002, and 2004, respectively – the quantity of new wind capacity projects fell dramatically, reducing the growth of carbon abatement opportunities. Even without an explicit lapse in the PTC, the threat of a lapse discourages the marginal investor from undertaking the upfront investment. In general, fiscal constraints lead to inherent uncertainties about subsidies, which limit their practical effectiveness.

7. POTENTIAL ALTERNATIVE INSTRUMENT COMBINATIONS

In this section, we provide three examples of how alternative instrument combinations can mimic the outcomes of an ideal carbon tax. A Pigovian tax creates both a set of substitution effects and a set of output effects, and the multiple instruments can replicate all such effects. The principle at work here is to imagine what would occur under a carbon tax, and then induce those outcomes by other means. The three examples in this section are not meant to be a comprehensive list of all possible carbon tax outcomes or alternative instrument combinations to achieve those outcomes, but we provide them here for intuition about how such mechanisms can operate. Table 1 contains a summary of the three examples: replace old vehicles with new hybrids, increase biofuel use, and reduce solo commuting. Below, we explain the examples in detail.

Before doing so, however, we note the extreme difficulty of setting each standard or subsidy in an efficient mix of multiple instruments. Cost-efficiency requires pursuing each abatement method until its marginal abatement cost (MAC) is the same as for each other method of abatement. See Figure 6. Too much or too little incentive for any one abatement activity means that the achieved total abatement is more expensive than if achieved from a Pigovian tax on all sources of carbon dioxide. To set each separate incentive or standard, the policymaker would need much data on the marginal abatement cost of each activity.

Table 1. **Examples of Alternative Instrument Combinations to Mimic an Unavailable Carbon Tax on Vehicle Emissions**

Example	**Carbon Tax Outcome**	**Alternative Instruments**	
		Substitution Effect	Output Effect
1	Replace Old Vehicles with New Hybrids	Mandate Hybrid Sales	Subsidize Scrapping
2	Increase Biofuel Use	Subsidize Blending	Tax Mileage
3	Reduce Solo Commuting	Subsidize Mass Transit	Tax Solo Drivers

7.1. First Example: Scrap Old Vehicles plus Mandate Hybrids

One outcome of a carbon tax is that some individuals would scrap their old, high-carbon vehicles, and *some* of them would buy a new hybrid or other fuel efficient vehicle. A substitution effect is the switching of vehicles, but an output effect is that *some* individuals might do without a car at all. Without a carbon tax, one might think that policy could subsidize the purchase of hybrid and other fuel efficient vehicles. That subsidy could achieve the substitution effect, but it would not encourage others to go without a car at all. Thus, the replication of effects of a carbon tax would require the *combination* of a subsidy or mandate to increase sales of hybrid vehicles and a cash subsidy to scrap existing vehicles. By itself, a hybrid mandate can encourage producers to cross-subsidize sales so that marginal consumers purchase new hybrids instead of other new vehicles (the substitution effect). However, the mandate provides no incentive for existing high-carbon vehicle drivers to scrap their vehicles, because the cost of driving does not change. The subsidy for scraping high-carbon vehicles increases the opportunity cost of continuing to operate the old vehicles, and thus it creates the incentive to reduce the number of high-carbon vehicles on the roads (i.e. output effect).

7.2. Second Example: Biofuel Subsidy plus Miles Tax

Another result of an "ideal" carbon tax would be an increase in biofuel use by vehicles, displacing traditional gasoline and diesel. In lieu of a carbon tax, subsidizing biofuel blending and taxing vehicle-miles can mimic the same outcomes. The blending subsidy makes it profitable for refiners to substitute away from 100 percent petroleum-based gasoline. However, the subsidy might reduce the price of fuel. Cheaper fuel may induce individuals to drive more. Therefore, driving needs to be discouraged, and a miles tax can achieve that goal. Recently, global positioning system (GPS) technology has fallen dramatically in price, so requiring GPS on all new vehicles can help make a miles tax enforceable.

7.3. Third Example: Mass Transit plus Tax on Solo Driving

Fewer solo commuters would also result from the implementation of a carbon tax, as the cost of gasoline increases. However, other means of transportation can substitute for driving to work, such as public transit. Thus, subsidizing public transit by lowering the cost per bus ride or subway trip encourages individuals to substitute away from driving. The subsidy would increase public transit ridership, but under a carbon tax, these new riders may have been telecommuting to work instead of physically commuting. Therefore, another instrument needs to reduce the number solo commuters among those still driving. A tax on solo commuters entering a city center creates the desired output effect.

8. ADDITIONAL COMPLEXITY

When considering combinations of alternative instruments to mimic an ideal but unavailable carbon tax on vehicle emissions, many factors complicate the calculations needed to calibrate the right amount of incentives to provide to each separate abatement activity. In this section, we identify additional sources of complexity: vehicle portfolio choice, uncertainty and learning, fleet dynamics, and infrastructure. These additional sources do not comprehensively cover all of the dimensions of complexity, but they do provide an insight into the challenging issues confronting policymakers in their design process – if they are to achieve economically efficient combinations of abatement choices without using a tax on carbon.

8.1. Vehicle Portfolio Choice

Many households make a complicated joint decision about their portfolio of vehicles. In 2000, almost 60 percent of all households in the United States owned two or more vehicles. These vehicles provide different amenities such as fuel efficiency, number of seats, cargo capacity, and off-road capabilities. For example, a single household often owns both a small, fuel-efficient car for commuting to work and a large, gas-guzzling sport utility vehicle for weekend and group activities. The vehicle portfolio choice becomes important when implementing instruments to promote low-carbon vehicle adoption at the household level, such as a tax credit that can be applied to joint tax return.

8.2. Uncertainty and Learning

New technologies such as hybrid and all-electric vehicles lead to uncertainty and information constraints among potential consumers. In their own self interest, producers have an incentive to advertise these new vehicles to encourage sales, but to the extent that helpful information does not reach everyone, supplemental information campaigns provide a public good. In addition, individuals can learn about new technology from their neighbours, family, and friends. Therefore, temporary policies that subsidize new vehicle technology adoption by some families can also help other families to resolve uncertainty about how hybrids and all-electric vehicles perform.

8.3. Fleet Dynamics

Vehicles are expensive durable goods that individuals and corporations do not replace regularly. The stock nature of the vehicle fleet leads to lags in full adoption of abatement opportunities, when policies provide incentives to switch away from high-carbon vehicles. In other words, policies that apply only to new vehicles will require time to take full effect. Credit constraints may exacerbate the lag. This lag is important because trying to retrofit all existing vehicles is infeasible for many types of low-carbon technologies.

This problem affects not only the time it takes to achieve carbon dioxide reductions, but indeed whether reductions occur at all. If low-carbon technology mandates apply only to new cars and are expensive, then owners of older cars may decide to delay the purchase of a new low-carbon vehicle. If so, then the nationwide average vehicle age may increase, emissions per mile may increase, and total emissions may increase (Gruenspecht, 1982). This logic suggests a subsidy to new low-carbon vehicles rather than a mandate, plus a subsidy to scrap old vehicles.

8.4. Infrastructure

Another complicating issue is the interaction between urban planning, highway engineering, and the amount of traffic congestion. Sitting in slow or stopped traffic burns extra fuel and wastes time, and politicians often call for the building of additional lanes to ease the flow of vehicle traffic. However, Anthony Downs in 1962 observed that the number of vehicle-miles grows in proportion to the length of available highway lanes. This phenomenon became known as the Fundamental Law of Highway Congestion (FLHC) and was recently confirmed by Duranton and Turner (2009) using updated statistical techniques. As a consequence, a policy to reduce carbon emissions by building more highway lanes is unlikely to succeed. Instead of building new lanes, California lets hybrid vehicles with specific registration stickers use the High Occupancy Vehicle (HOV) lanes that had previously been reserved for buses and carpools. But the FLHC still applies, because new highway lanes became available despite no construction. Besides providing more lanes for vehicles, urban planners and highway engineers can invent creative solutions to allow free-flowing traffic, and economic policy can provide incentives for alternate commuting behaviour such as non-peak driving and telecommuting.

9. CONCLUSION

This paper demonstrates how alternative policy combinations can mimic an ideal but unavailable carbon tax on vehicle emissions. When calibrated correctly, these instruments can replicate all of the substitution effects and output effects of the ideal Pigovian tax. The economic principle governing the use of these alternative instruments is to consider the multiple and diverse effects of a carbon tax, and then implement multiple policies to achieve that same set of outcomes. Moreover, using mandates and subsidies eliminates some political constraints, as part of a holistic approach to reducing carbon emissions. We also discuss key policy objectives such as economic efficiency, equity, enforceability, and fiscal sustainability. We discuss key complicating factors such as individual heterogeneity, vehicle portfolio choice, uncertainty and learning, fleet dynamics, and infrastructure. All of these objectives and complicating factors need to be considered when implementing multiple policies using alternative instruments.

NOTES

1. From here on, we use "carbon" as a synonym for all greenhouse-gases unless otherwise specified.

2. The jump may be more apparent than real, for two reasons. First, the scale on the right-hand vertical axis shows much finer gradation than the left-hand scale; the numbers are not very different from each other. Second, the vehicle occupancy rate survey changes calibration in 2001, so the jump might just be a data adjustment issue.

3. Light Trucks exceeding 8500lbs are still exempt through 2011. The NHTSA website states that "The most recent light truck rulemaking for model years 2008-2011 brought in large SUVs referred to "medium duty passenger vehicles" (MDPVs) in model year 2011 and beyond."

4. The federal tax is 18.4 cents per gallon. State taxes range from 8 cents for Alaska to 46.6 cents for California. They average to 28.5 cents, so the total federal and state rate is 46.9 cents per gallon.

5. Existing fuel taxes in Europe may be too high or too low relative to marginal damages from multiple externalities (carbon emissions, local pollutant emissions, congestion, and increased risk of accidents). Even if overall fuel taxes roughly match marginal environmental damages, however, they are currently based on energy content of the different fuels, and on other political factors, not based on carbon content. Thus the relative prices of the different fuels do not induce the reductions in the use of each fuel that would represent the most efficient forms of carbon emission abatement.

6. The range of $20-$300 per ton is suggested by Parry, et al (2007) in their survey of automobile externalities. They draw from a range of other published sources that are referenced in their paper.

7. See http://www.washingtonpost.com/wp-dyn/content/article/2010/02/05/AR2010020504790.html for an article in *The Washington Post*, dated February 7, 2010 (entitled "Racking up miles? Maybe not").

8. The current or proposed CAFE standard in the U.S. may be too high or too low, depending on several factors. One problem is to determine the correct shadow price of carbon (in the range of $20-$300 per ton of carbon as mentioned above). Another problem is that the appropriate CAFE standard in the mix of multiple instruments depends inherently on the stringency of the other instruments in the mix.

9. The subsidy to newness in that model is effective because newer cars are cleaner than old cars, both because emission rates deteriorate with age of the vehicle and because newer vintages face stricter standards. That study looks at local pollutants, and it assumes one vehicle per household. For carbon emissions, such a program is only effective if newer cars have lower carbon emission rates. And if the total number of cars is not fixed, then a subsidy to buying a new car is not equivalent to a subsidy for scrapping an old car.

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