Transportation and Urban Air Pollution Policies for Developed and Developing Countries

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Improvements in urban air quality remain elusive in large cities throughout the world, including those in the United States where efforts have continued over 20 years to reduce emissions from vehicles and other sources. Although technological advances in gasoline and diesel-fueled vehicles and in their emission control systems and fuel have resulted in impressive emissions reductions, the combination of more vehicle-miles traveled and other factors offsets these improvements. Tightening further vehicle emissions standards in developed countries would be costly and—judging by the continuing presence of ambient ozone in urban areas—ineffective policy. Rather, efforts to target high-emissions vehicles and to impose fees on fuels, vehicles, or emissions may prove to be more cost-effective. For developing countries, the removal of lead from motor fuels and imposition of economic incentives to control transportation are potentially cost-effective strategies.

The further tightening of vehicle emissions standards in the U.S. Clean Air Act Amendments of 1990, the worldwide effort to develop alternate-fueled vehicles, and the rapid growth of vehicle use in developing countries provide ample evidence of the pivotal role to be played by vehicles in strategies for improving urban air quality, enhancing energy security, and addressing global warming concerns. Yet, technological, economic, and environmental trade-offs complicate the fashioning of strategies to meet any one of these goals, let alone all of them at once.

Of all these issues, that of urban air quality is particularly frustrating. Technological improvements in gasoline- and diesel-fueled vehicles, their emissions control systems, and the fuel they use have resulted in impressive emissions reductions. For instance, emissions of volatile organic compounds (VOCs) (precursors of ambient ozone) fell 33 percent over the 1980 to 1989 period (*1*). However, these reductions have not improved ambient ozone concentrations in U.S. cities, with some 66 million people still living in 96 urban areas that violate the U.S. ambient ozone standard (*2*). The growth in vehicle-miles traveled (VMTs) by 39 percent over the same period (*2*) is one of the major culprits.

Outside of the United States the story is similar (where data permit a story to be told). Many of the largest urban areas in OECD (Organization for Economic Cooperation and Development) countries and South America likewise record concentrations of CO and NO_x (another ozone precursor) above World Health Organization (WHO) air quality guidelines (*3*). Some of the worst air pollution in the world is in major cities in developing countries, such as Mexico City, and, with growing incomes, vehicle ownership and VMTs will skyrocket, leading to more severe air quality problems.

These problems are being approached on a variety of fronts, but with less regard to economic principles than is warranted. In any country, but particularly developing countries, scarce resources should be allocated to maximizing net social benefits. By designing policies that are sensitive to both the costs of obtaining emissions reductions and the benefits derived, this goal can be approached. As these costs and benefits may vary with level of development, among other factors, the efficient set of policies may differ according to stage of development as well.

Some of the benefits, costs, and policy issues associated with reducing urban vehicular air pollution in developed and developing countries are addressed. The benefits of controlling each type of emissions are examined, as well as the relative contributions to urban emissions made by vehicles. Then, a variety of vehicle emissions control policies are examined for their ability to deliver cost-effective emissions reductions. These policies include developing alternate fuels and vehicles, targeting high-polluting vehicles, using transportation controls, and introducing broader economic incentives, such as emissions fees. Focus on benefits and costs is used to guide and organize the discussion, but a full-blown benefit-cost analysis is not presented. The role of vehicles in producing greenhouse gases and the complex interplay between policies addressing fuel economy and those addressing air pollutants are ignored.

BENEFITS

All fossil-fuel burning vehicles emit the conventional pollutants: sulfur dioxide (SO_2), particulates, VOCs, nitrogen oxides (NO_x), carbon dioxide (CO_2) (and small quantities of other greenhouse gases), and carbon monoxide (CO). The VOCs and NO_2 are precursors to ambient ozone (O_3). Some VOCs are carcinogenic, such as benzene; some particulates are also carcinogenic, such as benzo(a)pyrene and other polycyclic aromatic hydrocarbons (PAHs). Significant quantities of lead are also present as additives in leaded gasoline.

Each type of emission from a vehicle has its own dose-response functions that relate exposure to a pollutant to the amount of injury. Because of the different proportion of emissions of various types in gasoline and diesel exhausts, policies that favor one fuel over another will affect the mix of urban

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emissions and the damages caused, even if VMTs remain constant. To be informed about these trade-offs, information on the health and other effects of the various types of pollutants is needed. Because a policy can cause certain types of health and other effects to increase while others diminish, a comparison of effects requires using a common metric, such as dollar values. Several available estimates of the effects and benefits of controlling various air pollutants emitted by vehicles are described in the following paragraphs. For comparability, they are converted to a per-mile basis.

The effects are limited to those on human health. It is the health damages associated with ozone formed from its precursors—VOCs and NO_x—as well as health effects related to carbon monoxide emissions and, in developing countries, particulate emissions that are fueling concern over vehicular emissions.

O_3

The effects of ozone on health are the most well understood of any conventional pollutant-health interaction. The short-term effects of ozone [respiratory symptoms after 2-hr exposure, daily symptoms, restrictive activity days (RADs), and asthma attacks] are firmly established and quantifiable (within fairly narrow uncertainty bounds) using both clinical and epidemiological studies (*4*). There is currently much debate over long-term effects of ozone on lung tissue and the probability of developing chronic respiratory disease.

The acute health benefits of ozone reductions are calculated as the acute health effects reductions associated with reduced ozone exposure multiplied by the value people place on avoiding such effects. Acute health benefits for a 35 percent reduction in VOC emissions in the northeast United States have been estimated to range between \$100 and \$2,000 per ton with a best estimate of around \$500 per ton (*5*). This contrasts with cost benchmarks of \$10,000 per ton and more (*6*). On a per-mile basis, the benefits per ton translate [at 1.75 grams per mile (g/mi), EPA's estimate of VOC emissions from current gasoline vehicles (*7*)] to benefits per 10,000 mi of \$0.40 to \$8.00, with a best estimate of \$2.00. Said another way, with 73 million people living in this area, benefits range from about \$2 to \$33 annually per person.

CO

CO at ambient levels may increase the probability of experiencing angina for an estimated 5 to 7 million people in the United States who are at risk (a prevalence rate of 3 percent). However, in spite of much effort expended to identify health effects of this pollutant at ambient levels, too little information is available to derive exposure-response functions (*8*).

NO_x

The direct effects of NO_x emissions appear to be of little health significance in the aggregate. The acute health effects from ambient NO_2 exposure appear to be minor (*9*). Further, EPA says that there is presently no reliable scientific evidence of adverse effects in humans for long-term NO_2 exposure at ambient levels (*10*). The fact that NO_2 is 17 times less reactive an oxidant than ozone may account for the difficulties in finding effects.

Particulates and SO_2

In contrast, there is more concern about, but not a good understanding of, the effects of SO_2 and particulates on health; but concern is muted by the fact that few areas, at least in the United States, are violating current air quality standards. The direct effects of SO_2 on health in the United States have been strongly linked to exercising asthmatics exposed for brief periods (1 hr) to SO_2 concentration spikes that are occasionally experienced in the United States. In general, SO_2 and particulates, and their combination, have been linked to increased risks of acute and chronic morbidity and mortality (*11*).

On the basis of a recent epidemiological study (*12*), Portney et al. (*13*) found mortality risk reductions in Los Angeles (with 12 million people) ranging from 0 to 4,000 statistical lives saved annually as a result of the Los Angeles air quality plan (*10*) to reduce sulfate concentrations by about 50 percent (in part with controls on vehicles and diesel fuel). Multiplying this figure by an estimate for the value of a statistical life (from the economics literature)—\$1 million—yields benefits ranging from \$0 to \$4 billion. However, as only about 4,000 people died of respiratory causes in the Los Angeles area in 1988 (personal communication, Los Angeles Department of Public Health), the upper range estimate cannot be viewed as credible. In any event, benefits range from \$0 to \$300 per person, with a best estimate of about \$150. Assuming that the benefits are realized entirely through particulate reductions (projected to be 1,331 tons per day by the South Coast Authorities) and using the diesel particulate estimates in grams per mile presented in Table 1, a best estimate of mortality benefits is about \$29 per 10,000 heavy-duty diesel (HDD) miles displaced [or \$5 per 10,000 light-duty diesel (LDD) miles displaced]. Adding morbidity benefits of \$700 million estimated by the South Coast (*14*) yields estimates of benefits ranging from \$0 to \$78 per 10,000 HDD miles displaced, with a best estimate of \$39. For LDDs, the range is \$0 to \$14 with a best estimate of \$7. These benefit estimates are substantially larger than for ozone.

Lead (Pb)

Finally, consider one of the most important unconventional vehicular pollutants—Pb. The relationship of changes in Pb in gasoline to changes in blood lead levels in the U.S. population is remarkably close (*8*). Thus, unlike other pollutants, there is little uncertainty about the effects of reducing Pb in gasoline on Pb exposure. There is also general agreement that children with high-typical blood Pb levels suffer learning disabilities and recent studies link ambient Pb exposure to high blood pressure. With this link, Pb becomes a risk factor for hypertension, heart attacks, and stroke, particularly in men.

EPA (*8*) estimated the physical and monetary benefits of the Pb phase-down regulations [which reduced Pb in gasoline

TABLE 1 AVERAGE TAILPIPE EMISSIONS (g/mi) (FEDERAL TEST PROCEDURE CYCLE)

	POLLUTANTS								
				HC		Particulates			
VEHICLE TYPE	CO	NO_x	SO_2 [f]	THC	Benzene	Total	BaP	SO_4 [c]	Pb
Diesel								0.037	
Heavy-Duty	10	28	1.6			3.2[c] (1.4)[d]	54		
Light-Duty	3	1	0.53	0.23[a,b]	0.02	0.6[c] (0.4)[d]	13		0.0[i]
Gasoline								0.006	
No Catalyst	15	4	0.1	5.4[a,b]	0.31	0.1	20		0.020
Catalyst	5	2	0.07	1.8[b]	0.06	0.02	0.4		
U.S. Late Model	8[h]	1.39[g]		.72[g]					
U.S. VEHICLE TAILPIPE EMISSIONS STANDARDS									
Light-Duty Diesel Trucks	10.0	1.2		0.8		0.26			
Light-Duty Gasoline Passenger Vehicles & Trucks	3.4	1.0		0.41		0.6(<1987) 0.2(≥1987)			

a. 1975-82 models.
b. Diesels emit heavier alkanes, which have greater ozone-forming potential.
c. Mostly fine particulates (≤ 1 um).
d. Field experiments in a tunnel.
e. Accounts for nearly 20% of particulate matter mass, mostly as H_2SO_4.
f. Diesel sulfur content of 0.3% (U.S.).
g. EPA (1989c). 50,000 mile in-use.
h. CARB (1989). 50,000 mile in-use.
i. The source mistakenly had 0.019 g/m. Lead is not added to diesel fuel. Unlike for gasoline, the octane enhancement provided by lead makes diesel engines perform worse.

Source: EPA (1990).

from 1.1 to 0.1 grams per leaded gallon (gplg)] for the above endpoints, concluding that the costs of reducing lead (far less than 1 cent per gallon) were far outweighed by a lower bound estimate of the benefits. EPA predicted benefits in avoided medical costs and special education classes of $600 million annually for children with Pb levels brought below 25 μg/dl and benefits of $5.9 billion for men between 40 and 59 years old in reduced risk of premature death from heart attack, reduced incidence of hypertension, and reduced incidence of stroke and nonfatal heart attack. With overall benefits of $6.5 billion, 28.8 billion miles traveled on leaded gas in 1986, and assuming average passenger vehicle fuel economy of 18 miles per gallon in 1986, benefits average about $12 per 10,000 mi, again higher than for controlling ambient ozone, and also exceeding that for LDDs.

EMISSIONS SHARES

In fashioning efficient emissions control policies, knowledge of the relative share of total emissions created by particular types of vehicles (gasoline versus diesel, automobile versus scooters, etc.) is important. If large reductions in emissions are desired, emissions from the vehicle types contributing the largest shares need to be controlled.

The contribution of vehicles to air pollution in an urban area depends on the use of vehicles relative to activity levels of other sources of emissions, on the mix of vehicles, the presence and operation of pollution controls on the vehicles, and the quality of the fuel being burned.

In the United States and most developed countries, there are credible estimates of the contribution of vehicles to total emissions by pollutant. These data for the United States (*15*) indicate that vehicles contribute 45 percent of the VOCs in ozone nonattainment areas, although this share varies across U.S. urban areas from a low of 30 percent to a high, in Los Angeles, of about 66 percent. Vehicular NO_x emissions were only about 30 percent of the total nationwide in 1989 (*1*), but are higher in urban areas. CO emissions are dominated by vehicles. Comparing gasoline and diesel vehicle emissions, gasoline vehicles dominate in all categories of emissions except SO_2.

Yet, controlling diesel emissions can still be productive on a per-mile basis. Table 1 presents average U.S. tailpipe emissions coefficients for HDD and LDD trucks and for passenger and light-duty gasoline vehicles with and without catalytic converters. The most comparable figures are between gasoline vehicles with catalytic converters and LDDs. Of the conventional pollutants, sulfur oxides are over five times larger, and total particulates are 30 times higher for the LDDs, with sulfates about six times larger (mostly in the form of sulfuric acid), whereas CO, NO_x, and HCs (a slightly broader measure of hydrocarbons than VOCs) are substantially lower for LDDs (*16*).

The comparison for particulates is even more unfavorable than it looks, because nearly all of the diesel particulates are fine (and therefore can penetrate deeply into the lung) and some carcinogens such as benzo(a)pyrene, are also far more heavily represented in diesel emissions than in gasoline emissions. According to WHO (*3*), diesel engines generate 10 times more respirable particulates than gasoline engines per kilometer traveled.

The comparison between gasoline vehicles (in this case automobiles) and diesel vehicles (i.e., buses) can be further sharpened by comparing emissions per passenger-mile. Assuming that bus emissions are the same as those for heavy-duty diesel in Table 1, an average of 20 passengers per mile on a bus and one person per mile in an automobile would equate NO_x emissions per passenger-mile between a bus and a late model automobile. For SO_2, 23 passengers, and for particulates, 160 passengers. Thus, in the United States, where transit buses carry only an average of 10 people per mile (*17*), buses would still be more polluting.

In developing countries, data limitations mean that the emissions share of vehicles needs to be inferred. Certainly, transportation is a major activity in developing countries, given that it claims 25 percent of their energy use (except India and China) (*18*). Dependence on trucks and buses is far greater than in developed countries—more than 50 percent of total energy demand comes from trucks and a large additional share from buses (*19*). In terms of passenger trips in motorized vehicles, about 50 percent occur in buses (*20*). Two- and three-wheeled two-stroke vehicles, which can produce high levels of pollution in spite of their fuel economy, also make up a larger share of urban road transport in developing than in developed countries. They are particularly prevalent in cities such as Singapore, which has one motorcycle for every 3.5 automobiles. Also, vehicles are responsible for much of the CO and ozone problems experienced in the largest urban areas of developing countries.

Whatever estimates are available on emissions from vehicles in developing countries appear to support the emphasis on diesel emissions and two- and three-wheel vehicles. In Indian cities, two- and three-wheeled vehicles were estimated to be responsible for 85 percent of the CO and 35 to 65 percent of the hydrocarbons (*21*). Diesel trucks and buses were estimated to have created 90 percent of the NO_x. A recent study (*20*) estimates that for nine developing countries buses and trucks (as separate categories) are each a larger source of total emissions of all types than automobiles, except for CO in Thailand and Tunisia. In three Latin American countries, total emissions of CO and HC were estimated to be larger for automobiles, whereas buses and trucks emit the largest share of SO_x. Particulates and NO_x were not found to exhibit any clear trend.

In many urban areas, air pollution from vehicles appears to be of lesser current concern because vehicle ownership and VMTs are so low. According to the United Nations (*22*), automobiles per 1,000 urban dwellers are nearly always less than 100 and generally less than 50 in developing countries, while ranging from 200 to 500 per 1,000 in developed countries. Yet, of six developing countries reporting VMTs in 1977 and 1987, all experienced increases, ranging from 23 to 250 percent (versus 33 percent in the United States). In Indonesia, vehicle ownership tripled from 1970 to 1981, in Brazil and Lagos it more than doubled, in Nigeria it increased five times. With a doubling of cities with over 4 million people by 2000 (*3*), vehicle use is clearly going to continue its rapid increase.

Emissions, at least on a per-mile basis, are already likely to be higher for the average vehicle in developing countries than in developed countries. This is so because the former tends to be older and less well maintained and less likely to have any emissions control equipment. For example, in Mexico City, 70 percent of gasoline vehicles and 85 percent of diesel vehicles participating in a voluntary inspection and maintenance program fail the emissions tests. Less than half the vehicles in Mexico have pollution control devices of any kind and none have state-of-the-art systems. However, on a passenger-mile basis, bus emissions (as well as automobile emissions) would be far lower than their U.S. counterparts because of the high load factors of buses (and automobiles) in developing country cities. More data are needed to determine which mode has the net advantage in emissions per passenger-mile and what the cost effectiveness would be of reducing emissions for each mode.

There is little ambiguity about the large share of urban Pb emissions from vehicles and the tight relationship between reducing this source of Pb and blood Pb levels. Furthermore, the benefits of avoiding exposure to Pb emissions have been estimated to be large and relatively certain compared to some other pollutants and relative to the costs of reducing or eliminating Pb additives. Thus, phasing out of leaded gasoline deserves a high priority. Beyond this, firm conclusions are harder to make.

In particular, difficult choices loom for developed countries. There, passenger vehicles contribute a large proportion of urban VOCs, NO_x and CO, thereby contributing importantly to violations of ambient O_3 and CO standards. Diesel vehicles, which are only a small part of the vehicle fleet in developed countries, contribute (at least in the United States) most of the vehicular particulates and SO_2 on a per-mile basis, but not in the aggregate. Most urban areas of developed countries are not violating particulate and SO_2 standards. At the same time, the health effects are not well understood for CO and, for O_3, those that are well understood are relatively unimportant and not highly valued in the aggregate when compared to heath effects potentially caused by particulates and SO_2. Should the dominant vehicle type—the gasoline-fueled automobile—come in for most of the control even though its emissions are perhaps more benign than those of diesels?

For all but the largest urban areas of developing countries, vehicular emissions are probably less of a problem and, at least for now, the choices are less clouded. Vehicles in these areas are likely to emit larger amounts of all types of pollutants per mile traveled but, with so many fewer miles traveled and such poor controls on other urban sources of pollutants, particularly those emitting particulates, control of vehicle emissions may not be a major issue. Future growth in urban incomes will change this situation in the future, however, bringing the air quality of many more urban areas down to that of the large primary cities in developing countries. The modal split favoring buses, trucks, and two-stroke scooters over automobiles in developing countries (with the reverse true in developed countries), the poor maintenance and advancing age of the bus fleet, and its associated high levels of emissions per mile, the use of high-sulfur fuel by buses and trucks [in the United States, sulfur content is 0.3 percent, to be reduced to 0.05 percent, whereas in the Philippines it is 1 percent (*20*)], and the potentially high value of benefits from reductions in fine particulates implies that developing countries might be better off focusing on control of these diesel sources rather than on control of automobiles.

POLICY IMPLICATIONS

As long as national air quality standards are generally set on the basis of protecting health rather than balancing costs and benefits, urban air quality policies will be inefficient. Nevertheless, there is still a broad scope for the application of economic concepts in the design of cost-effective pollution control policies involving vehicular emissions. In this section, four types of policies are reviewed for their likely cost effectiveness with respect to one another and in developed versus developing countries.

Vehicle-Fuel Technologies

The primary strategy for reducing vehicular emissions in developed countries has been that of setting tailpipe emissions standards on gasoline vehicles. This strategy has resulted in lower tailpipe emissions primarily through the technological advance of the catalytic converter. Indeed, some more recent advances have enabled some late model year vehicles to meet the very stringent 50,000-mi standards set in the 1990 U.S. Clean Air Act Amendents for 1994 (*23*).

Germany, the Netherlands, Norway, and Sweden have, until recently, taken another route. Each taxed clean cars less than others (or reduced annual vehicle fees) but clean was defined mainly as having a catalytic converter, not in terms of specific types of emissions. These policies were slated for removal in 1989 as United States–style EC-wide vehicle emissions standards will make such differentiation unnecessary (*24*).

Developing countries generally do not have emissions standards, with vehicles emitting at levels consistent with the technology for emissions reductions embodied in them or, if the technology is not working, at uncontrolled levels. Pre-1969 vehicles purchased from any manufacturer would emit at uncontrolled levels.

Cost-effectiveness analyses of the progressive tightening of the U.S. emissions standards suggest that some reductions in vehicle emissions are cost effective (i.e., in comparison to the costs of other emissions reduction options), but that these costs increase rapidly with more stringent standards (*25*). Absent technological breakthroughs in emissions controls or reformulated gasoline, the newest round of emissions reductions in the United States is likely to be even less cost effective. However, for developing countries that have never set requirements on vehicular emissions, relatively lenient emissions standards may prove cost effective.

The mounting frustration with reducing the external effects (environmental and energy security) of gasoline vehicles has led to increasing attention being paid to a set of technologies involving new fuels and vehicles. The new U.S. Clean Air Act, for instance, requires gasoline to be reformulated to have lower ozone-forming potential, more oxygen, and fewer carcinogens, and diesel fuel to have no more than 0.05 percent sulfur content. Although no other alternate-fueled vehicles are mentioned in the Act, very stringent standards in areas with serious air quality problems open the door to them. Alternate-fueled vehicles being considered include methanol, ethanol, compressed natural gas (CNG) (and LNG), and electric vehicles (EVs) (as well as hybrids), with hydrogen and solar vehicles further off in time.

Numerous reviews of the advantages and disadvantages of these options (*26*) have failed to identify a clear frontrunner on grounds of costs and emissions reductions. One fuel-vehicle mix being particularly touted in the U.S.—methanol—has been estimated (*6*) to be a costly option in terms of the reductions in ozone-forming potential that it delivers relative to improved and advanced gasoline vehicles—with a best estimate of costs for M100 vehicles (vehicles that burn 100 percent methanol) of $51,000 per ton of VOCs displaced.

The main drawback of relying on advances in technology for emissions reductions—and this applies at least as much to alternate fuel vehicles as to gasoline vehicles—is that its effectiveness is dependent on turnover in the vehicle stock. This has two implications. First, this strategy is for the long run, as such turnover takes much time; for developing countries, the wait will be even longer because vehicles are held for longer periods than in developed countries. Second, if the new technologies are more expensive than the old and have characteristics that make the vehicles less attractive to consumers, the rate of turnover is likely to slow. Crandall et al. (*25*) found (using an earlier version of EPA's MOBILE4 model) that higher new vehicle prices as a result of the 1981 tightening of emissions standards had the effect of increasing VOCs and CO emissions over that of a scenario where standards were not tightened, and that this perverse effect lasted for 5 years. Overall, they found that in 1982 the aging of the vehicle stock from its 1967 to 1978 average resulted in VOCs, CO, and NO_x emissions being 26, 23, and 11 percent larger, respectively, than they would have been had no aging occurred.

Given the dependence of the success of most of the new fuel-vehicle strategies on consumer acceptance of new vehicle technologies, strategies involving reformulated gasoline (both leaded and unleaded) and reduced sulfur in diesel fuel have more appeal because they can be applied at once to the entire vehicle stock. They also may be reasonably low cost. Formulation changes to reduce gasoline volatility are the most cost-effective option identified by the Office of Technology Assessment ($500 per ton of VOCs reduced) (*15*); ARCO's EC-1 formulation for precatalytic vehicles has a cost effectiveness in reducing hydrocarbons of about $4300/ton, if a 20 percent emissions reduction to a 1979 model year can be obtained for $0.02 per gallon (*27*). Another cost advantage is that reformulated gasoline can be used selectively in areas that have the worst air quality.

Taking the perspective of developing countries, development of alternate-fueled vehicles is generally outside of their ability to influence (the potential market being too small). In addition, advanced emissions control technologies generally require advanced equipment and specialized knowledge to service. Given the already poor state of maintenance of vehicles in developing countries, only specially designed low-maintenance, reliable, and low-cost technologies are likely to make inroads into developing country vehicle markets. Until developing countries switch to unleaded fuels (leaded fuel poisons the catalytic converter), even current catalyst technologies will be beyond their reach.

As seen for developed countries, reformulated gasoline and low-sulfur diesel fuel strategies are promising innovations for developing countries. Given the continued use of leaded fuel in the latter countries, ARCO's EC–1 leaded gasoline is particularly promising if the 2 cents/gal cost differential in the United States would apply to these countries as well. Given the heavy dependence of Asian countries on highly polluting two-stroke motor scooters, successful penetration of gasoline-powered two- and three-wheeled motorized vehicles would improve the air.

Targeting High-Polluting Vehicles

Even in the United States, there has been little effort to identify and mitigate emissions from high-polluting vehicles—the 10 percent of the U.S. vehicle fleet that, according to some sources, is responsible for half the vehicle emissions (*28*). Until recently, the consensus was that the oldest vehicles were the grossest polluters. In this case, fleet turnover would eventually take care of the problem. Older vehicles, because they embody older emissions control technology, do produce more emissions per mile than newer vehicles, on average. A pre-1981 passenger vehicle produces three times the HCs, twice the NO_x, and eight times the CO as a new vehicle (*27*). In the United States, pre-1981 passenger vehicles account for 71 percent of all vehicular HC emissions.

Unfortunately, matters are more complicated than this. Recent research indicates that there is wide variation in emissions performance of vehicles within any given model year. ARCO found that the most polluting of 16 pre-1981 vehicles produced nearly 10 times the HCs of the least polluting. General Motors has also found wide vehicle-to-vehicle variation in emissions, with the distribution of emissions roughly log-normal: at 50,000 mi, 10 percent of 1986 model year vehicles violate the HC standard, 27 perΣN1i =0 ΣN2j =0ijz⁻i1z⁻j2j cent violate the CO standard, and 7 percent violate the NO_x standard (*29*).

Inspection and maintenance (I&M) programs are the primary approach used to address this problem in the United States and other developed countries, but are rarely used in developing countries. However, these programs (at least in the United States) have some major drawbacks: (a) they test cars while they are idle and warm, rather than running or cold, when most of the emissions are emitted; (b) some do not have strict enough penalties for failure to correct violations or even have the car inspected; (c) pass rates are very high, meaning that administrative costs are high to catch the few violators; and (d) those that fail are not required to spend more than a set limit on repairs. This waiver feature leaves vehicles with serious pollution problems still on the road. In addition, (e) very old vehicles are exempted from the program.

In order to better target high-emitting vehicles, Stedman (*28*) recommends using infrared sensors placed on highways to read CO emissions (which are highly correlated with HC emissions) of passing vehicles, take photographs of heavy polluters, and therefore permit officials to require that these vehicles be brought to inspection stations. Unfortunately, the technology is still in the experimental stage.

Programs to identify and prematurely retire, maintain, or relocate high-polluting vehicles, can be potentially well-targeted, cost-effective emissions reduction strategies. The American Petroleum Institute (API) (*27*) considered a variety of alternatives to address the high-polluting vehicle problem, including differential registration fees and vehicle retirement programs. Most developed countries charge registration fees that are constant for all vehicles. Japan, for instance, charges from $250 to $500 per vehicle, whereas the U.S. fees range from $15 to $40. Higher fees, even if undifferentiated by model year or emissions, would tend to encourage scrapping lower-valued vehicles, although the extent of this effect is unknown. Higher fees for older vehicles, while better targeted for pollution reductions, would likely be highly regressive, i.e., politically unpalatable. Charging higher fees for more-polluting vehicles, irrespective of age, is really an emissions tax, discussed in the following paragraphs.

Vehicle retirement programs have begun in California. The most interesting involves the purchase of pre-1971 vehicles by Unocal Corporation for $700 each, for what it hopes will count as emissions credit against emissions from its industrial operations. This privatization of pollution reductions could deliver large cost-savings to the company, estimated to be about $161,000 per ton of VOCs (*30*). The issue for society is whether the vehicles purchased would be scrapped anyway, i.e., whether the emissions reductions are real. Also as currently structured the actual emissions of the vehicle are not taken into account. By basing vehicle purchase prices on emission tests results, emissions reductions could be obtained more cost effectively. Finally, some further screening would help improve efficiency by ensuring that the purchase price did not exceed the price of repairs. API suggests that only vehicles failing the I&M tests and that cannot be repaired within the waiver limits be eligible for purchase.

While I&M programs are sorely needed in developing countries, some observers are quite pessimistic that they can be implemented and run efficiently (*20*). At the same time, with a much higher percentage of the vehicle stock made up of poorly maintained and older vehicles, there is little reason to be concerned about targeting. As noted earlier, cleaner gasoline and low-maintenance vehicles constitute a more reliable, but not necessarily less expensive, option for emissions control.

Transport Controls

Controls on the flow of traffic, e.g., alternative drive-days, no-vehicle zones in city centers, high parking fees, HOV lanes, etc., can have a direct effect on the environment if total VMTs fall or trips are switched to less polluting modes of transport, and an indirect effect if congestion is reduced.

At lower speeds, vehicle emissions per unit distance are higher for most (though not all) pollutants. Hydrocarbon (HC) and carbon monoxide (CO) emissions are twice as large at 15 mph as they are at 30 mph (although NO_x emissions are halved) for automobiles in the United States (*20*). These effects could be particularly important for pollutants that do not disperse far, such as CO.

Both developed and developing countries are increasingly experimenting with transportation controls as a means of improving traffic flow and reducing emissions. European countries have been in the forefront of applying controls, such as restricting traffic in central business districts (CBDs).

Transportation controls can reduce emissions efficiently in general and in developing countries. First, transportation controls have the advantage of being local in nature, and can therefore be fine-tuned, at least in theory, to local conditions. Second, such controls generally have low expenditures associated with them, although nonmonetary costs, in terms of (say) inconvenience and longer commutes, may be inferred to be large, given the resistance to efforts at changing driving and overall commuting behavior.

Third, transportation controls may be more effective in and attractive to developing countries than developed countries. Transportation controls have not been particularly successful in developed countries, in part because preferences for automobile travel, urban design and infrastructure, and transport choices are largely fixed. These features are far less fixed in fast-growing areas of developing countries. If the value of time and comfort is lower in developing countries, some of the nonmonetary costs of transport controls may be lower as well.

Some developing countries have already instituted transport control programs using economic incentives. Congestion tolls have been tried. For example, a Mexico City policy whereby admittance to the CBD on a given weekday depends on one's license plate number, appears to have had some effect in reducing traffic and smog levels in the city. Singapore's Area License Scheme, which required purchase of a sticker to enter the city during the morning rush-hour (current price = $2.60/day) and was supplemented by parking fees and a park-and-ride service has also been judged a qualified success: a 75 percent decrease in vehicles entering the area during the morning rush hour, a 20 percent increase in bus commuters, a doubling of car pools (*31*), and substantial reductions in downtown air pollution (*32*).

In effect, the sticker policy confers a property right to car owners, or more precisely it creates a property right in what was previously a common property resource. However, the right is not transferable because it is determined by the license plate. An improvement would be to issue certificates or stickers for travel on a given day, perhaps on the basis of license plate number. A wrinkle would be to allow these certificates to be traded or sold; the ensuing market would help ensure that stickers would flow toward those with the greatest willingness to pay to enter the city.

An experiment in Hong Kong (*33*) exhibited the potential for moving towards congestion tolls of a more optimal nature, although this is more realistic for developed countries. By fitting cars with license plates capable of being scanned by computers set up at key arteries within the city, vehicles were to be charged roughly by the amount of driving they did. The plan was ultimately rejected because of concern over what would happen to the collected revenues. However, advances in such technologies and their merger with technologies being tried out in California to measure CO emissions from vehicles waiting to enter Los Angeles freeways could make it possible to charge vehicles for their contribution to congestion and pollution.

Fourth, although some types of transportation controls may be attractive to developing countries, expanding public transit—a long-standing favorite urban transport strategy—is not likely to be one of them. Because of the large share of commuting by bus and the chronic undercapacity of this system in many cities, scope for increasing use of buses is limited, unless capacity is increased, an expensive option. One approach might be to encourage privatization of bus service, an approach judged to have been successful in Calcutta, Mexico City, and Bogotá (*34*). Another approach is to make bus companies, whether private or public, more financially sound by permitting their subsidized fares to increase. An ancillary effect of higher fares might be to improve maintenance of bus engines. The effect of improved maintenance on reducing emissions might be more than enough to offset emissions from any increase in bus capacity.

Fifth, beyond public transportation subsidies, existing perverse incentives on use of vehicles could be reduced. Both developed and developing countries subsidize automobiles and truck use rather than tax or otherwise restrict their use on environmental grounds. For instance, in many cities, parking costs only about 50 cents per day; trucks pay road taxes that are far less than proportionate to the damage they do to roads (*35*); and diesel fuel is often subsidized (in India it is about half the gasoline price) as a way of promoting economic development. Such subsidies may distort transportation choices. In the case of diesel fuel, the subsidy may artificially disadvantage barge and rail carriers.

Finally, the earlier analysis suggests that any policies that encourage modal shifts away from gasoline vehicles to diesel vehicles may involve complex health trade-offs—increasing (highly uncertain) mortality effects from fine particulates present in diesel emissions while reducing (much more certain but less severe) respiratory distress from automobile-related ambient ozone exposures. Analysis of the relative costs and health benefits of reducing pollution from diesel versus gasoline engines is needed to better focus these policymaking efforts.

Emissions Fees

In contrast to the prominent place occupied by what might be called the "mainline" economic incentive approaches—emissions fees, energy taxes, and tradable permits—in the debate over how best to reduce CO_2 emissions (*36*) and acid rain precursors (resolved in the new U.S. Clean Air Act in favor of tradable permits), little discussion of these tools can be found in the debate over policy design for improving urban air. This is unfortunate as such tools, at least in developed countries with the administrative and legal infrastructure to use them, can help bring about low-cost attainment of air quality goals.

For instance, a set of emissions fees that varies by fuel-vehicle type depending on the extent of the environmental externalities created by use would go a long way to encourage (a) reduction of VMTs, (b) mode switching to more environmentally benign forms of transport, (c) research and development of fuels and vehicles that result in low emissions, and (d) more rapid turnover of high-polluting or, at least, older vehicles (depending on how the fee system was structured). Fees levied on any specific fuel, vehicle, or characteristic (such as fuel economy or carbon content) cannot deliver all of these benefits and may distort choices and outcomes away from being socially beneficial. Taxes on oil only, for instance, may reduce the attractiveness of gasoline vehicles but, by not accounting for the polluting characteristics of all fuels, may not give enough incentive to develop and market the fuels that have the lowest social cost (private cost plus external cost).

One further benefit of emissions taxes can be obtained if they are used to replace value-added, excise, or other types of product-based taxes. These taxes distort market prices and associated consumer choices (i.e., consumption versus leisure choices) and, therefore, result in social losses, what economists call "deadweight losses of taxation" (*37*). By replacing such taxes with emissions fees, the full social costs of these products is reflected in price and the deadweight losses are removed. Sweden's plans for replacing its value-added taxes on energy with revenue-neutral environmental taxes are in this spirit (*38*).

CONCLUSION

Tailpipe emissions standards on passenger vehicles have resulted in impressive reductions in VOC, CO, and NO_x emissions per mile in the United States and will doubtlessly do so as other developed countries follow the U.S. approach. Nevertheless, these reductions have come at a high cost and, more important, have failed to significantly improve urban air quality, in part because of increases in VMT. At the same time, by raising new vehicle prices, the mandated standards have slowed vehicle turnover, keeping dirtier vehicles on the road longer, and delaying penetration of the newer, far cleaner models. However, an undeniably wise national-level strategy, based on benefit-cost considerations, has been to phase out leaded gasoline and to reduce sulfur in diesel fuel.

What the latest round of policymaking in the United States suggests is that the future holds more of the same, in the sense of maintaining the focus on vehicle emissions standards without a reasonably certain prospect that air quality (at least in terms of ambient O_3) will improve. By setting these standards below a limit that automobile makers and oil companies say can be reached by gasoline vehicles with or without reformulated gasoline, a major mandate has been placed on alternate fuels and vehicles, though none as yet have the combination of cost effectiveness and consumer acceptance to make them an efficient alternative to gasoline vehicles. Meanwhile, promising options, such as targeting high-emitting vehicles, go begging at the federal level.

Virtually unexplored but much debated are emissions fees and energy taxes that take into account the environmental and other external benefits of reducing various types of emissions. European governments appear more willing to consider and implement this approach than the United States (*24*), but the movement in the United States and elsewhere to internalize environmental costs in electricity supply decisions and prices (*39*) may do much to legitimize and further the application of emissions fees and energy taxes in the transportation sector.

The promising policies for developing countries are different from those for the developed countries. A targeting strategy may be less effective for developing countries, because most vehicles probably have high emissions. Whether inspection and maintenance programs can be effectively operated is also an open question. Penetration of alternate-fueled vehicles will be limited by lower baseline vehicle turnover rates, greater sensitivity of vehicle demand to price, and the need for less sophisticated, low-maintenance technologies. However, the clear health benefits from reducing Pb in gasoline and sulfur in diesel fuel make these fuel improvement strategies a priority. Transportation controls (including, for instance, removal of subsidies to parking, bus fares, and diesel fuel, as well as sticker programs as implemented in Singapore) offer some promise of cost-effectiveness, particularly if they can be instituted before commuting and freight transport patterns become hardened. Because of the possibly large health effects associated with diesel bus emissions relative to those of gasoline passenger automobiles, expansion of the latter at the expense of the former may not be all bad. In any event, reducing subsidies to public bus systems or encouraging their privatization are two ideas for placing bus service on firmer financial footing, with associated reductions in emissions resulting from poor maintenance and an aged capital stock.

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