The Journal of Private Enterprise 23(2), 2008, 65-80

The Potential of Satellites to Control Pollution from Motor Vehicles

Gregory B. Christainsen*
California State University, East Bay

Abstract

This paper argues that onboard diagnostic systems linked via vehicle transponders to satellites could provide the basis for a more efficient and potentially global approach to controlling pollution from motor vehicles. Motorists would be subject to multiple emissions charges: (1) a one-time charge when a vehicle is first sold; (2) a recurring charge that would depend on the distance driven during each period of time; and (3) an additional charge in the event of improperly maintained equipment pertaining to pollution abatement. The use of transponders and satellites for (2) and (3) would make conventional smog testing obsolete and would result in large cost savings.

I. Introduction

In light of recent developments in satellite technology, this paper discusses a provocative and potentially global approach to the burning of fossil fuels by motor vehicles. The approach raises several questions – as does any plausible approach to motor vehicle pollution. The paper will address some of the more important questions in the space available, but it should not be viewed as the last say on the matter. Rather, it is intended to be part of an ongoing discussion.

During the last 40 years, governments have required that new vehicles meet ever-tougher emissions standards. However, a disproportionate amount of the pollution from motor vehicles comes from older vehicles (U.S. Environmental Protection Agency, 2000),[1] and the more stringent emissions standards for new vehicles make

* This paper was originally prepared for the 2007 conference of the Association for Private Enterprise Education. The author would like to thank two anonymous referees and the editor for helpful comments. The usual disclaimer applies.

[1] For more recent data, see *USA Today*, 18 June 2007, A1.

them more expensive and actually encourage people to retain ownership of older vehicles for a longer period of time than would otherwise be the case.

In areas that have been behind schedule in meeting federal air quality standards, older vehicles can be required to pass a smog test as a condition for remaining on the road. That is very costly, however, in terms of both out-of-pocket expenses and drivers' time to have millions of vehicles brought in to be checked. Cheating on smog tests is also thought to be widespread.

As an alternative, economists have frequently recommended that vehicles be charged directly for their emissions, regardless of whether the vehicles are new or old. But most such proposals have still relied on motorists to bring in their vehicles to be checked, at least in terms of the distance that they have been driven during a particular period of time. Thus, some policymakers have simply recommended that older vehicles be charged higher registration fees or that factories or oil refineries be given credit for pollution reductions if they buy up older vehicles and take them off the road.

Efforts to place "remote sensing" devices near freeway on-ramps and off-ramps or at other strategic locations to try to detect high-emission vehicles (without these vehicles needing to be checked at service stations) have been intriguing (e.g., Klein, 2003), but somewhat controversial. The U.S. Environmental Protection Agency (EPA) has viewed remote sensing as a complement to, but not a substitute for, ordinary smog tests (U.S. Environmental Protection Agency, 1994). Some of the concerns expressed by the EPA – for example, the feasibility of assessing vehicles' emissions of nitrogen oxides – have already been addressed or may be resolved in the near future. As this paper will discuss, remote sensing merits continued consideration, but whether it should be the main way by which vehicle emissions are monitored remains an open question.

Satellite monitoring of vehicles is a more recent and exciting development. Satellites are now used to levy emissions charges on trucks driving on Germany's autobahns (SPC Media, 2007). Satellite charging has been tested and seriously considered in Hong Kong as well (Wilbur Smith Associates, 2000).

This paper links the discussion to the more general issue of how to best price the use of roadways. Singapore began pricing entry into its Central Business District in 1975, and it now employs more extensive – and electronic – pricing that varies according to vehicle

type and traffic conditions (Christainsen, 2006). London introduced congestion pricing inside its inner-ring road in 2003 (New York Academy of Sciences, 2007). Stockholm launched a pilot pricing program in its downtown area in 2006. A permanent road pricing program began in 2007 (Stockholmsforsoket, 2007).

Road pricing exists in a few other places as well, but outside of Germany, satellites remain an untapped mechanism for charging vehicles. While it can be readily seen that satellites offer a potentially global approach to the management of traffic congestion and vehicle pollution, there remain sensitive issues involving civil liberties and government control over the satellites themselves.

Section II of this paper outlines U.S. policies with respect to pollution from motor vehicles. Section III discusses the possible use of emissions charges vs. direct controls over emissions or vehicle gas mileage. Subsidies for alternative fuels that are alleged to be less polluting than fossil fuels (e.g., ethanol) are also discussed.

Section IV of the paper looks at the technological and administrative issues relevant to the use of satellites or related technology for assessing emissions charges. The use of satellites as opposed to remote sensing (without satellites) is discussed. Germany serves as a case study in satellite charging; its experiences can be compared to places like Singapore that already have electronic road pricing that is not based on satellites. Hong Kong is also worth mentioning insofar as it has conducted field tests that have attempted to assess the efficacy of satellite use.

Section V discusses the possibility of extending ordinary liability law to those deemed responsible for motor vehicle pollution. Section VI offers a tentative conclusion to the paper, but it must be emphasized that the relevant technologies (and their costs) are still evolving.

II. U.S. Policies Regarding Pollution from Motor Vehicles

The federal Clean Air Act, which was signed into law in 1963, has dominated American policy. The Act is administered through the U.S. Environmental Protection Agency. As we shall see, California has also been especially noteworthy for its pollution control initiatives. Federal legislation regarding the so-called corporate average fuel economy (CAFE) of motor vehicles has been in place since 1975, and is administered through the U.S. Department of Transportation.

The 1977 Clean Air Act amendments divided the country into two main parts: those areas whose air quality was in compliance with federal air-quality standards, and those areas whose air quality was not in compliance. The 1977 amendments required that states with nonattainment areas institute inspection and maintenance programs for vehicles already on the road. This has meant that vehicles registered in nonattainment areas must be brought into service stations or other facilities for periodic smog tests and checks of their pollution abatement equipment.

In 1987 the California Air Resources Board required that all new vehicles sold in California starting in manufacturer's year 1988 have onboard diagnostics capability. This involves outfitting a vehicle with myriad sensors that give the owner or a repair technician access to state-of-health information for various vehicle sub-systems, including the equipment pertaining to pollution abatement. The 1987 California requirements are generally referred to as the "OBD-I" standard, though this name was not applied until "OBD-II" rules were issued by the U.S. Environmental Protection Agency. The 1990 amendments to the federal Clean Air Act mandated the OBD-II rules, which became effective for new vehicles in 1996.

Early versions of onboard diagnostic systems simply illuminated a malfunction indicator light if a problem inside a vehicle was detected, but no information was provided as to the nature of the problem. More recent technology includes a high-speed digital communications port to provide vehicle data in real time as well as a standardized series of diagnostic trouble codes. These codes enable technicians to quickly identify and remedy vehicle malfunctions.

The 1990 amendments to the Clean Air Act also contained a measure under which certain nonattainment areas were required to establish programs for the adoption of clean fuel vehicles by centrally managed vehicle fleets. California now requires that vehicle manufacturers sell a certain number of "clean vehicles" as a condition for selling any vehicles (of any kind) in the state.

III. Emissions Charges vs. Direct Emissions Controls, Mandates for "Clean" Vehicles, Subsidies for "Clean" Fuels, or Mandates for Greater Fuel Economy

As emphasized by F. A. Hayek (1978), the market is a discovery process. The optimal amount of anything cannot be known in advance. No one knows ahead of time the "right" number of pencils,

file cabinet drawers, bicycle reflector lights, or Phillips screwdrivers, but we can be confident that the outcome of the market is quite efficient in the sense that business enterprises have incentives to produce these items as long as (and only as long as) people value them as much or more than the costs of providing them. The lowest cost way of providing each item is also subject to discovery.

Just as with pencils, the "right" amount of motor vehicle pollution abatement is unknowable in advance. Nor can the lowest cost method of abatement be known ahead of time. Even if government officials had such knowledge, public choice theory, spearheaded by James Buchanan and Gordon Tullock (1962), emphasizes that there might still be considerable inefficiency. The political process is not the same as the market process because it lacks the same system of property rights. The decisions necessary to attract campaign contributions and votes and to secure administrative positions may be economically perverse. Thus, even if government officials did know the right amount of abatement and the lowest cost way of doing it, they might not enact legislation that is economically efficient.

Direct emissions controls are inefficient if emissions could have been abated at less cost with a different approach. They are also inefficient if, for the same cost, people put a higher value on something besides cleaner air.

The primary federal air pollution standards are based on human health considerations. In other areas of life, however, people often accept health risks in exchange for other benefits. For example, people may eat ice cream even though they are aware that it has significant amounts of unhealthy cholesterol. The mere act of riding in a motor vehicle involves accepting some amount of risk to life and limb.

The current system of vehicle emissions controls is grossly inefficient in two other ways. First, early on, Arnold Reitze (1979, p.735) pointed out that, even if one took a conservative view of what the costs were, the costs of abating pollution via inspection and maintenance programs were two to three times higher than the costs of abating the same pollutants via regulation of factories and other stationary sources of emissions.

Second, most motor vehicle pollution comes from a relatively small number of high-emission vehicles. Most vehicles run fairly cleanly (University of Denver, 2007). Insofar as the problem vehicles

can be identified, much cleaner air could be had at much less cost if the great majority of vehicles that run fairly cleanly were, for the most part, left alone. Remote sensing and satellite monitoring of vehicles have considerable appeal in this regard.

Requiring that a certain percentage of the new vehicles sold has zero (or quite low) emissions is objectionable because it does nothing to weigh benefits and costs. Such an approach presumes knowledge on the part of government officials that they, in fact, do not have. No one can know in advance the right number of low-emission vehicles. Officials who themselves bear only a trivial portion of the total costs of government policies may nevertheless have public choice incentives to show that they are "doing something" about pollution by mandating their production.

It should therefore also be clear that corporate average fuel economy requirements – "CAFÉ standards" – are objectionable as well. Given their cost and their encouragement for the manufacture of lighter, but less safe vehicles (other things equal), who really knows the "right" gas mileage for motor vehicles?

Simply charging a vehicle for emissions, regardless of vehicle age, has great appeal to economists because it obviates at least a good part of the Hayekian knowledge problem. If vehicle owners could be held directly responsible for their emissions, car buyers could then be left free to buy any vehicles they like. Some buyers might buy high-emission cars or cars with relatively poor gas mileage, but they would then be subject to comparatively heavy emissions charges. Others might opt for low-emission (or even zero-emission) vehicles and/or vehicles with extremely good gas mileage, but these vehicles might be relatively expensive. Some vehicle owners might decide that the most economical course of action would be to upgrade the pollution control equipment on a car they already have. Once emissions charges were in place, it would be up to the market to sort out the emissions and equipment characteristics of the various vehicles and the number of vehicles of each type to be produced. The gas mileage of vehicles would likewise be a market-determined outcome.

Whether vehicles would even run on gasoline could not be known in advance for all time. Some demand for corn-based ethanol might exist, but with charges in place on vehicles (and/or ordinary gasoline), its production would no longer plausibly justify a separate subsidy. It might be desirable to buy a vehicle that runs on an even cleaner fuel – hydrogen? Solar power?

The main point is that government officials, even if they be intelligent people, are not competent to micromanage the outcomes in a reasonable way. The fact that corn-based ethanol is simultaneously mandated, subsidized, *and* subject to import restrictions – a 54 cent per gallon tariff – makes clear that politicians are often more concerned about protecting farmers' interests than they are in an efficient approach to motor vehicle pollution.

However, any system of emissions charges itself faces difficult issues. A somewhat flawed system of charges might still be superior to more extensive government command and control, but the problems should not be denied. First and foremost is the question of how high the charges should be for the various pollutants. Should they not differ by location? In places where pollution is a severe problem, it would be efficient to have higher charges. In other areas, it would be appropriate to have lower charges or no charges at all. From the standpoint of neoclassical economics, an efficient charge would be equal to the pollution damages attributable to an incremental vehicle.

There is a public choice problem as well as a knowledge problem. If government officials are involved in levying charges, might not the levies be distorted by political considerations? Governments are currently responsible for managing most roadways. Why do most major metropolitan areas lack *any* road pricing, let alone efficient road pricing? If emissions charges are economically efficient, why haven't government officials already enacted them?

Aside from these fundamental questions, there are more practical concerns about how a charge system would be implemented. When such ideas were initially discussed, the most prominent proposals were those made by Lawrence J. White (1973, 1976, 1982). In his pollution control scheme, a charge would be assessed on each new vehicle dependent on the average emissions level of vehicles in its class. Vehicles would thereafter be subject to periodic smog tests. At the conclusion of each smog test, a new charge would be levied based on the vehicle's current emission level and the distance that the vehicle had been driven since the previous charge had been assessed. Charges would vary by location.

As with inspection and maintenance programs generally, the main practical drawback of White's proposals was the requirement that all vehicles be inspected on a regular basis. As mentioned, this devours, in the aggregate, a tremendous amount of people's time in addition to

the out-of-pocket expenses involved. Since most vehicle pollution is caused by a modest number of heavy polluters, such programs are akin to frisking the whole population to catch a small group of serious pickpockets.

IV. Technology, Remote Sensing, and Satellite Charging

1. Remote Sensing as an Alternative to Conventional Smog Tests

Remote sensing represents a valiant effort to detect high-emitting vehicles without needing to bring all vehicles in to be inspected at service stations. Unlike most equipment used to measure vehicle emissions today, remote sensing devices do not need to be physically connected to the vehicle.

Remote sensing systems employ an infrared absorption principle to measure emissions. They operate by continuously projecting a beam of infrared radiation across a roadway. The system's detectors receive strong infrared light signals through the air when no vehicle emissions are in the path. If some amount of pollution is present in the path, it will absorb some of the light at the pollutant's unique wavelength.

Remote sensing systems are capable of making all of the calculations necessary to assess a vehicle's pollution characteristics in just 0.7 seconds. The systems also employ a freeze-frame video camera and equipment to digitize a color image of the rear of the tested vehicle, including the license plate. This allows the system to store emissions information for each monitored vehicle based on the license plate number. Since the unit is permanently installed in a van, it can be set up quickly without affecting the traffic flow. The unit can be moved from one site to another throughout an area. However, at present no states rely exclusively on remote sensing to check vehicle emissions. The plausible, nonpolitical reasons for this include:

(1) Current remote sensing systems can measure tailpipe emissions of hydrocarbons, carbon monoxide, carbon dioxide, and nitrogen oxides, but they cannot measure the evaporative emissions that vent directly into the air because of defective gas caps or fuel lines. Evaporative emissions are a very significant source of hydrocarbon pollution. The pollution can exceed that from tailpipe emissions on hot days when ozone levels are highest (U.S. Environmental Protection Agency, 1994). Remote sensing systems are also not very advanced in detecting emissions of particulate

matter, although their performance in this regard seems likely to improve. Finally, such systems are even more handicapped in detecting emissions of lead, although leaded gasoline was banned from general use in 1995.

(2) Remote sensing systems cannot identify vehicles with defective pollution abatement equipment, even in cases where a vehicle's dashboard has an illuminated malfunction light, unless the vehicle has already been emitting high amounts of pollution.

(3) Identifying a majority of the high-emitting vehicles might require a very large number of tests throughout a metropolitan area – perhaps in the hundreds of thousands or millions over a multi-year period. To save on testing costs, it might then be necessary simply to threaten high-emitters with very large fines on the understanding that many high-emitters would not, in fact, be detected. As with any system of emissions charges, a decision would need to be made about how high the charges would be. Political considerations could affect charges and the choice of testing locations. Thus, while remote sensing has attractive features in terms of focusing on gross polluters (Klein, 2003), it also faces at least some knowledge and public choice problems.

2. Satellites

Satellites and related technology (e.g., cellular telephones) now make possible an alternative approach. This approach is arguably simpler, more proactive, more comprehensive in terms of geography and pollutants covered, and more economical than ferrying remote sensing equipment all over metropolitan areas. It also makes use of the onboard diagnostics that have been standard in new vehicles since 1996 and links them to a transponder.

This possibility is already being called OBD-III, to distinguish it from OBD-II, which does not involve a transponder. The transponder would have the ability to transmit diagnostic data instantaneously to a control center via the already-existing network of low-earth-orbit satellites. Thus, if pollution abatement equipment were not properly maintained, the control center would be informed immediately – without the necessity of bringing in the vehicle for a smog test. The sensors in the pollution abatement equipment are so proactive that a light appears on a driver's dashboard even before the vehicle's emissions level increases significantly. A transponder can also easily transmit information about the distance that a vehicle has

been driven during any given period of time.

Thus, as with White's original proposals, an emissions charge could be levied at the time a vehicle is purchased and additional charges assessed based on the distance a vehicle is driven over time. In the event that the diagnostic data indicate that equipment that is relevant to a vehicle's emissions needs repair, still another charge would be levied (perhaps after a modest grace period) until the problem was fixed. The charge could depend on the distance driven with the defective equipment.

Note that the system is capable of identifying defective gas caps and fuel lines as well as detecting problems with catalytic equipment and making odometer readings. It can also detect efforts to tamper with equipment. (Technology now available in newer vehicles allows onboard sensors to directly measure emissions that must otherwise be assessed by attaching a hose to the vehicle's tailpipe. However, this technology does not measure evaporative emissions.)

It would in any case be desirable to give credits, as California has done, to stationary source polluters (e.g., oil refineries) who buy up high-emitting vehicles and take them off the road. If it is cheaper for the stationary source simply to abate its own pollution, it would have an incentive to do so. The number of credits that a stationary source would get for taking a "clunker" off the road would depend on factors such as the remaining useful life of the vehicle and the estimated number of miles it would have been driven had it stayed in operation.

3. Germany as a Case Study of Satellite Charging

As is the case for the other approaches already discussed, satellite charging must also confront knowledge and public choice problems. In 2005 such charging began on the 12,000 kilometers of German autobahns for trucks with a maximum weight of 12 or more metric tons. Vehicles may pay charges manually in advance at service centers or online and obtain a receipt for doing so. Trucks with transponders are billed on a monthly basis. Charges vary with the distance driven, the number of axles, and the air pollution emissions class of the vehicle; these average out to about 0.12 euros per kilometer. The launch of the system was delayed, but it has since performed admirably. The upfront capital outlay was about 700 million euros. The technology for the system has been supplied and administered by Deutsche Telekom, Daimler Chrysler, Cofiroute (France),

EFKON (Austria), and, at a later stage, Siemens (SPC Media, 2007).

To ensure that toll evaders without transponders do not exist, the system requires that the satellites be supplemented with ground-level surveillance for the time being. This surveillance is accomplished via cameras and patrol cars. Cameras are positioned on close to 300 highway overpasses or other overhead structures, and nearly 300 patrol cars are involved in enforcement. Thus, there is about one overhead structure and one patrol car for every 40 kilometers of autobahn. In the future transponders may be standard equipment that could be outfitted with sensors as part of an onboard diagnostic system. The sensors could detect efforts to tamper with or disable transponders and would thereby greatly reduce enforcement costs.

Germany has thus joined Singapore, London, Stockholm, and a few other places in the vanguard of electronic road pricing. Singapore, London, and Stockholm stand out insofar as they conduct pricing in a quite deliberate effort to moderate traffic congestion on downtown streets. As far as motor vehicle pollution is concerned, it should be emphasized that vehicles stuck in traffic jams are themselves significant contributors to pollution concentrations. However, none of these cities employs satellites.

Hong Kong, which has a serious air pollution problem, has field-tested satellites as an alternative to the ground-level gantries employed in Singapore (Christainsen, 2006). Satellites were found to be just as reliable and more cost-effective once the number of pricing points in the metropolitan area reached 42 (Wilbur Smith Associates, 2000). Satellites thus performed quite well in the Hong Kong tests, but no action to institutionalize road pricing has been taken to date.

V. Emissions Charges and Legal Systems

While many environmental economists support the concept of emissions charges, some would ideally like to internalize pollution costs via the assignment of property rights to the resources in question (e.g., Anderson and Leal, 2001). It is perhaps easier to see how this can be done for water pollution than for air pollution. For example, if a factory polluted a stream, and property rights to the stream's flow of water were defined, the rights holder could file suit against the factory owner for damages. Alternatively, the rights holder and the factory could negotiate an arrangement under which the factory could continue to operate in certain ways and at certain times. Property rights would provide a backdrop against which the market

would determine the precise outcome. Pollution costs in the form of legal damages or agreed-upon precautions would thus be internalized by the factory owner and would need to be considered in any subsequent production decisions.

The most grandiose effort to assert property rights to the air in the case of motor vehicle pollution has probably been the case of *Roger J. Diamond v. General Motors.* This case was brought before a judge in the Superior Court of Los Angeles in 1971 (20 C.A. 3d 374 (1971)). The plaintiff, Roger J. Diamond, filed a class action suit on behalf of all property owners in Los Angeles. He named 293 defendants, including major automakers and oil refineries, and alleged that they had fouled the air of the property owners.

The judge threw out the case, calling it "unmanageable." He noted that in the common law a distinction exists between a private nuisance and a public nuisance. The former involves cases with a small number of people and very local activity. For example, if a neighbor of mine repeatedly hosts backyard barbecues that cause fumes to invade my property, I could conceivably sue him if efforts to persuade him to "tone it down" did not suffice. In the case of motor vehicle pollution, however, it would be extraordinarily difficult or impossible to say who precisely had damaged whom, and by what dollar amount. There are millions of people and millions of vehicles in the Los Angeles area, which is hundreds of square miles. Thus, the judge categorized motor vehicle pollution as a "public" nuisance, to be addressed by public regulation. However, as Roger Diamond himself stated in court, regulation may be subject to undue influence by the very parties who are subject to it – a familiar part of public choice theory.

With very little argument, Murray Rothbard (1997 [1982], p.161) maintained that, if roadways were privatized, the liability for motor vehicle pollution could and should be shifted to the roadway owners. Such an approach would change the names of the defendants to be charged in a massive class-action lawsuit,[2] but it would still be a

[2] Rothbard later (1997 [1982], p.164) argued that the joinder of multiple defendants in a lawsuit ought to be permitted only if they acted in concert. Since polluters do not generally act in concert, a victim of automobile pollution would thus have to sue vehicle owners (or roadway owners) one by one. He also argued that plaintiffs ought to show that the actions of the defendants caused them injury "beyond a reasonable doubt" (and not just by a "preponderance of the evidence," the norm for civil suits today). Rothbard recognized that it would then be virtually impossible

gigantic task to apportion damages among numerous roadway owners. How many private roadway owners would emerge in the Los Angeles area? Hundreds? Thousands? Nobody knows. Under a system of government-sponsored common law courts supplemented by legislation, it seems likely that courts would still hold that motor vehicle pollution is a "public" nuisance, although roadway owners might sometimes be held liable in very local cases involving traffic safety.

Of course, Rothbard was a famous proponent of anarchism, under which government-sponsored courts and legislation would no longer exist. He hoped for an ideological shift under which private courts would safeguard a regime of unfettered private property rights, absolute freedom of contract, and strict liability for torts. Christainsen (1990) argued that the rules emanating from a private legal system could not be preordained for all time, but would, in more Hayekian fashion, need to be subject to a continual process of market feedback and discovery. In this way, competing private courts could arguably confront the knowledge problem more capably than governments and uncover ever-evolving rules to limit pollution from motor vehicles. No one can say for sure whether the court enterprises would end up administering emissions charges, or whether they would opt for a completely different approach.

If we must instead rely on something like the current federal system to oversee the legal process, we must hope for a reasonable "constitutional contract," as envisioned by Buchanan and Tullock (1962). The constitutional contract would involve the federal government (or negotiations among state governments) insofar as air pollution spills over from one state to another, but would still rely on state and local governments in much of the decision-making. As matters stand, the federal government sets air quality standards and requires inspection and maintenance programs in areas that have not been in compliance with them, but the details of the policies to be implemented are formulated by the states and then submitted back to the federal government for approval. In a Buchanan and Tullock type of constitutional contract, states and localities would have great leeway in setting emissions charges, and residents could "vote with

---

for victims of automobile pollution to take effective action in court, but also argued that impracticality should not count against his vision of justice!

their feet" and move elsewhere if they were quite dissatisfied with the air quality and/or the emissions charges where they currently live.

VI. Conclusion

Motor vehicle pollution remains one of the most difficult of public policy challenges. While it is rather easy to criticize current policies, formulating an alternative that is both reasonably efficient and workable is a trying task. Advocates of free markets, who seem rather sure of themselves when discussing other issues, appear noticeably less confident when faced with the realities of emissions emanating from millions of mobile sources.

It will take time for all vehicles to include onboard diagnostics, but the process has advanced quite far at this point. Including transponders in the system will be another major step, but congestion as well as pollution issues are pushing public policy in that direction. As we have seen, congestion pricing is a natural complement to direct charges for pollution control because congestion tends to increase vehicle emissions. Satellite technology could be efficaciously used to administer both.

Concerns about civil liberties as well as purely economic ones are at stake. If government authorities will be monitoring vehicles via satellites and transponders, they could find out exactly where and when vehicles have been driven. This information may be relevant to efficient charging, but it may also be viewed as a threat to privacy. Credible safeguards must therefore be built into the system.

Singapore is not the best example of a place that respects privacy, but it is noteworthy in that its road pricing involves prepaid smart cards. These cards are inserted into vehicle transponders (which have become standard equipment), and charges are deducted from the balance on each card as vehicles pass under pricing gantries. *It is not necessary for the authorities to know the identity of a vehicle or who owns it unless there is some kind of violation* – i.e., no card has been inserted into the vehicle transponder, or the balance on the card is not sufficient to pay the charge in question. In any case, all records regarding the gantries under which vehicles have passed are destroyed within 24 hours except as they might pertain to an allegation that a vehicle was wrongfully charged.[3]

---

[3] Gopinath Menon, formerly Senior Manager, Land Transport Authority, Republic of Singapore, and one of the original architects of Singapore's road pricing system [personal communication].

A sophisticated set of emissions charges (and fuel taxes) would likely accelerate the current movement away from fossil fuels. As this paper has intimated, it remains to be seen whether real-world governments can administer charges very efficiently, but a better choice may not be available. Remote sensing of vehicle emissions should still be a part of the discussion, but the performance of the vehicle charging systems in Singapore, London, Stockholm, and Germany has been encouraging. Greater use of satellites and enhanced onboard diagnostics are the next frontier.

References

Anderson, Terry, and Donald Leal. 2001. *Free Market Environmentalism.* 2nd ed. Hampshire, UK: Palgrave Macmillan.

Buchanan, James, and Gordon Tullock. 1962. *The Calculus of Consent: Logical Foundations of Constitutional Democracy.* Ann Arbor: University of Michigan Press.

Christainsen, Gregory. 1990. "Law as a Discovery Procedure." *Cato Journal,* 9(3): 497–530.

Christainsen, Gregory. 2006. "Road Pricing in Singapore After Thirty Years." *Cato Journal,* 26(1): 71–88.

Hayek, F.A. 1978. "Competition as a Discovery Procedure." In *New Studies in Philosophy, Politics, Economics, and the History of Ideas*, 179–190. Chicago: University of Chicago Press.

Klein, Daniel. 2003. "Fencing the Airshed: Using Remote Sensing to Police Auto Emissions." In *The Half-Life of Policy Rationales: How Technology Affects Old Policy Issues*, eds. Fred Foldvary and Daniel Klein, 86–106. New York: New York University Press.

New York Academy of Sciences. 2007. Christine Van Lenten. "London Leads the Way." http://www.nyas.org/ebrief/miniEB.asp?eBriefID=644#meetingrep5200. (accessed November 9, 2007).

Reitze, Arnold. 1979. "Controlling Automotive Air Pollution through Inspection and Maintenance Programs." *George Washington Law Review,* 34(2): 723–748.

Rothbard, Murray. 1997. "Law, Property Rights, and Air Pollution." In *The Logic of Action Two*, 121–170. Cheltenham, UK: Edward Elgar, 1997. Originally published in *The Cato Journal,* 2(1): 55–99 (1982).

SPC Media. 2007. "LKW-Maut Electronic Toll Collection System for Heavy Goods Vehicles, Germany." http://www.roadtraffic-technology.com/projects/lkw-maut. (accessed November 9, 2007).

Stockholmsforsoket. 2007. "Evaluation Reports." http://www.stockholmsforsoket.se/templates/page.aspx?id=12555. (accessed November 9, 2007).

U.S. Environmental Protection Agency. 1994. "Automobile Emissions: An Overview." http://www.epa.gov/otaq/consumer/05-autos.pdf. (accessed November 9, 2007).

U.S. Environmental Protection Agency. 2000. "Emission Facts: Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks." http://www.epa.gov/otaq/consumer/f00013.htm. (accessed November 9, 2007).

University of Denver. 2007. Fuel Efficiency Automobile Test Data Center. "Fuel Efficiency Automobile Test Reports." http://www.feat.biochem.du.edu/reports.html. (accessed November 9, 2007).

White, Lawrence. 1973. "The Auto Pollution Muddle." *The Public Interest*, 32: 97–112.

White, Lawrence. 1976. "American Automotive Emissions Control Policy: A Review of the Reviews." *Journal of Environmental Economics and Management*, 2(4): 231–246.

White, Lawrence. 1982. "U.S. Automotive Emissions Controls: How Well Are They Working?" *American Economic Review*, 72(2): 115–119.

Wilbur Smith Associates. 2000. *The Hong Kong Electronic Road Pricing (ERP) Feasibility Study*. Hong Kong.