

Cato Institute Policy Analysis No. 249: The Smog-Reduction Road: Remote Sensing vs. The Clean Air Act

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Executive Summary

The 1992 amendments to the Clean Air Act mandated that local governments that violate federal ozone (urban smog) standards abide by a dizzying array of regulations, many of the most controversial of which--centralized state inspection and maintenance programs, carpooling requirements, zero-emission vehicle sales quotas, use of alternative fuels, and new-vehicle emission standards--are intended to control automobile emissions.

Both empirical evidence and candid reflection suggest that current approaches to vehicle pollution are extremely inefficient, economically costly, and of only limited help in improving air quality. The use of remote sensors, mobile, roadside emission-sensing devices, could do more to improve air quality than all other approaches combined at only a fraction of the cost. Moreover, a remote-sensing program would embody the concept that the polluter--not society at large--should pay for pollution. But remote sensing is largely neglected by the Clean Air Act.

A detailed examination of how such a program could be implemented in Los Angeles indicates that remote sensing would prove far more effective and about five times less costly than the current decentralized inspection and maintenance program, known as Smog-Check.

Accordingly, Congress should amend the Clean Air Act to allow states to adopt remote-sensing programs in place of the unpopular and less effective programs currently required by the act. Such a reform would be a boon to drivers everywhere and would better meet environmental goals.

Introduction

Automobile emissions control policy is now in an exciting period of reexamination and reform. New learning has advanced understanding of the problem, and new technologies have expanded the set of solutions to consider.

It is now understood that 10 percent of the vehicles on the road, the gross polluters, generate over 50 percent of the on-road carbon monoxide (CO). The same is true of hydrocarbon (HC) emissions. As Figures 1 and 2 show, in each case the cleanest 80 percent of cars--the low and marginal emitters--generate less than 12 percent of the pollution.

Furthermore, studies suggest that repairs significantly reduce emissions only for cars with high emissions. Repairs made to cars that are only marginally over their emissions standards do little to reduce emissions and often even increase them.[1] Because of the extreme skewness of emissions, as shown in the figures, and because most emissions reductions will come from the gross polluters, the chief task of a cost-effective program must be to focus on gross

polluters.

Remote sensors appear to be capable of doing just that. An infrared beam is shone across the road; as a car passes, the beam travels through the exhaust plume and is distorted by the gases. The sensor receiving the distorted beam can infer the pollutant concentrations in the exhaust. Remote sensors are very inexpensive and mobile and can be set up on many streets and highway ramps. As the infrared beam passes through the exhaust plume, a camera automatically snaps a picture of the license plate. If government can use remote sensors to identify gross polluters, it can clean the air at low cost to the public.

Regulators are beginning to show interest in remote sensing, but they have not yet recognized the full potential of the new technology. Unfortunately, the policy debate over auto emissions revolves around how exhaustive centralized inspection and maintenance should be; whether electric vehicles should be mandated; the extent to which mass transit, car pooling, and trip reduction measures should be required; and the degree to which additional emission control technologies should be mandated for both cars and gasoline pumps.

Figure 1
Carbon Monoxide Emissions
[Graph omitted.]

Source: Douglas R. Lawson, "Passing the Test--Human Behavior and California's Smog-Check Program," *Journal of Air & Waste Management Association* 43 (December 1993).

Note: The 3,755 vehicles were ranked from cleanest to dirtiest on the basis of percentage of CO emissions on the low-idle test, then divided into 10 equal groups or deciles. The contribution of each decile to total CO emissions for the entire sample is indicated by the height of the bar.

A typical example of the current regulatory approach is the 10-year-old Smog-Check program in California, which requires cars and light trucks to pass inspection every two years. Inspections are performed at approximately 9,000 private garages licensed by the state. That system has been unsuccessful. Some motorists get their grossly polluting cars through Smog-Check by tampering with them or bribing the private inspectors. Some inspectors tinker with some cars so they can pass the test. Some gross-polluting vehicles are unregistered and thus avoid Smog-Check altogether.[2] Furthermore, the program is more costly than it needs to be, since it requires all motorists, even the majority with clean cars, to incur the costs of obtaining a smog certificate.

Smog-Check is unsuccessful because vehicle owners can anticipate inspections and because cars must pass inspection only once every two years. On the other 729 days of the biennium motorists can drive dirty cars.

Figure 2
Hydrocarbon Emissions
[Graph omitted.]

Source: Douglas R. Lawson, "Passing the Test--Human Behavior and California's Smog-Check Program," *Journal of Air & Waste Management Association* 43 (December 1993).

Note: The 3,755 vehicles were ranked from cleanest to dirtiest on the basis of percentage of HC emissions on the low-idle test, then divided into 10 equal groups or deciles. The contribution of each decile to total HC emissions for the entire sample is indicated by the height of the bar.

The Environmental Protection Agency agrees that programs like California's are less effective than they should be, but it has identified the problems differently. The EPA says that the Smog-Check program falls short because the private garages both inspect and repair vehicles. That, the agency believes, creates a conflict of interest and tempts proprietors of Smog-Check stations to break the law. The EPA has called for the separation of inspection and repair. Under its proposed "centralized" program, cars would report every two years to one of a small number of central, contractor-run facilities for inspection and, if necessary, go to private garages for repairs. The proposed program design, in contrast to California's "decentralized" program, would probably reduce corruption and fraud, although the new facilities might

operate in haste if they were rewarded for throughput. The EPA has also called for the use of more expensive testing equipment, dynamometers, which are treadmill devices that run cars through a pattern of simulated stop-and-go driving.

Although the EPA's centralized program has some advantages, opponents have been pointing out serious flaws. The EPA proposal still allows motorists to anticipate the test, and hence some motorists might still tamper with their vehicles before the test, although doing so would be more difficult under the EPA program than under the current program. Although mechanics could make superficial adjustments to allow a vehicle to pass the test, they could not fix underlying problems. Finally, the program would be extremely expensive in that all or most motorists would be required to report for inspection at less convenient facilities.

In 1993 California resisted the EPA's demands, partly because state officials doubted that a centralized program would be much of an improvement over the current program and partly because they recognized that with remote sensing on the horizon it would be rash to sink large new investments in anticipated inspection. The conflict between California and the EPA was resolved, if only temporarily, by a Memorandum of Agreement in March 1994. The agreement includes a pilot project to compare different types of test-only equipment and a pilot remote-sensing study for Sacramento County and calls for setting up centralized facilities with the capacity to test 15 percent of vehicles in nonattainment areas. The 9,000 Smog-Check stations, except for possible equipment changes and new training, will carry on as before.

The agreement is only a temporary accommodation. The EPA continues to favor centralized inspection and has been promoting other command-and-control policies for California, such as mandated carpooling. Moreover, other states without the political muscle of California--such as Arizona, Virginia, Georgia, Pennsylvania, Maine, and Delaware--have also sought to challenge the EPA's auto inspection mandates with limited success. Of late, the EPA has been showing more flexibility and paying increased attention to remote sensing.[3]

This paper addresses the technology and potential economic effects of remote sensing, how remote sensing might be applied in the greater Los Angeles region as a test case, and how a near-term transition to remote sensing might be constructed.

Policymakers need a vision of where their efforts ought to be headed. Public discussion too often focuses on the near-term demands placed on policymakers. We need to discern the forest from the trees. Doing so provides a road map for Congress when it considers amendments to the Clean Air Act. Any reevaluation of the act should include provisions to allow state governments to adopt remote-sensing programs in lieu of the auto emissions regulations required by Congress.

Adam Smith Visits Los Angeles

Were the ghost of Adam Smith to come to modern-day Los Angeles, he would no doubt agree that the air is very bad and that government policy must control auto emissions. Furthermore, he would have some advice about how to do it.

Adam Smith explained in *The Wealth of Nations* that, as consumers seek various outputs in the marketplace, market processes arrange themselves to deliver those outputs. If performance at the output stage is effectively rewarded in the marketplace, such rewards will induce entrepreneurs to coordinate their activities, as though "led by an invisible hand," to promote an ultimate end "that was no part of their intentions." In the market we seek various outputs at the lowest prices, and we let entrepreneurs, interacting spontaneously, worry about the inputs.

When we go into a restaurant, for example, and order a crock of French onion soup, we specify only the desired output. We do not tell the chef how to slice the onions, grind the pepper, or grate the cheese. We do not tell the restaurant manager where to get the ingredients, how to store them, or how to train the employees. Customers merely specify the outputs, and, as Smith explained, entrepreneurs in the market attend to the inputs. Successful entrepreneurs are experts on local opportunities for effectively combining inputs, and they compete for customers by seeking to produce the outputs that customers desire.

When it comes to air quality, however, Smith would readily recognize that reducing vehicle emissions is one of those

desirable output goals for which, as he put it, "the profit could never repay the expense to any individual [who should privately seek to achieve the goal]."[4] Instead, the government, in its role as steward of the commons, must attend to the problem. But Smith's logic of incentives still applies: if technology permits, the government ought to address the problem by treating outputs directly, not by treating inputs.

Smith's market-based reasoning stands in sharp contrast to command-and-control policies, which aim to achieve output goals by specifying inputs. Advocates of command and control seem not to believe that, once outputs are specified, the market will respond to those incentives and arrange inputs appropriately. Smith sought to enlighten the command-and-control advocates of his day. He said that every individual can, "in his local situation, judge much better than any statesman" what inputs are most appropriate to producing his desired output. Smith notes the pitfall of command and control: "The statesman, who should attempt to direct private people . . . , would . . . load himself with a most unnecessary attention."[5]

Smith's market-based approach of treating outputs rather than inputs presupposes, of course, that there is a practical way of monitoring and policing performance at the output stage. Fortunately, there is a way of monitoring vehicle emissions directly, namely, remote sensing. Smith would favor a system that penalized motorists directly for excessive emissions and that otherwise left motorists and entrepreneurs free to arrange the inputs, appropriate to their "local situations," to avoid penalties.

Just as one man's ceiling is another man's floor, a good or service might be an output in one context and an input in another. That point is illustrated by Figure 3, a conceptual diagram of the California automobile inspection and maintenance (I&M) program. The state's output goal is reduction of fleet emissions. To that end, it runs the Smog-Check program. Passing the test is, from the state's point of view, part of its production process. But from the motorist's point of view, passing the test is the output goal. One way motorists or their mechanics attain that goal is to keep their cars running clean. But other ways to attain the goal are to tamper with cars to temporarily reduce emissions and to obtain smog certificates illegitimately. Because those and other problems are common, the connection between the state's goal and the motorist's goal is weak and distant. The state is mandating an input process that does not deliver. Furthermore, it is comparatively expensive.

A remote-sensing program would better connect the state's and the motorist's output goals (Figure 4). The state would pursue its output goal by specifying a program that used on-road remote sensors and a system for sending citations to gross polluters. For motorists, the output goal would be avoiding smog citations. That program would be output oriented because the connection between the state's goal and the motorist's goal is strong and close. Furthermore, the program would be comparatively inexpensive.

Figure 3
Input-Output Diagram for Smog-Check Program
[Figure omitted.]

Figure 4
Input-Output Diagram for a Remote-Sensing Program
[Figure omitted]

Remote sensing of emissions would be an effective output-oriented program. Even though the technology is not perfect, remote sensing would be a major step toward cost-effective emission control, and it is time to think about how its deployment might render other auto-emission control programs obsolete.

Treating Outputs Rather Than Inputs

State inspection and maintenance are an input-oriented strategy. Passing an I&M test is not directly connected to the desired output--reduced auto emissions. It is an input in a process that, one hopes, produces the desired output. It is wiser for the government to treat auto-emission outputs, using pervasive and unanticipated remote-sensing surveillance, than inputs, such as anticipated inspections. There are five fundamental points, and each is illustrated by actual experience with I&M programs.

1. Strategies that specify inputs tend to be unrefined to individual conditions; that is, they tend to be one-size-fits-all. Yet the technique for transforming inputs into outputs is not singular but plural. Every motorist has his own distinct opportunities for getting his car to run clean. And, in the absence of input regimentation by government, the entrepreneurship of the market would discover better ways to keep cars clean. Required inspection by a certified station lays down a blanket procedure for getting cars clean, a procedure that forsakes special opportunities and diverse conditions and chokes off entrepreneurial creativity.

State I&M programs force most motorists to participate in a biennial practice that they may not need. About 70 percent of motorists have clean-running cars for all relevant pollutants, but most of them must participate in an input ritual (state inspection and maintenance) that is potentially appropriate for only the other 30 percent of cars.[6] And motorists in that dirty 30 percent might be able to make their cars clean by obtaining proper and legitimate service from unlicensed stations or unlicensed inspectors. In the absence of input mandates, entrepreneurs would come up with better and less expensive ways of serving the motorist's desire to avoid smog penalties.

2. A government program that specifies inputs runs the risk of specifying the wrong inputs. Government proceeds by the blunt forces of democratic and bureaucratic politics. Instead of relying on competitive market selection of inputs, government adopts input strategies that may well be ineffective in producing the desired outputs.

I&M programs have not lived up to their original promise. Independent researchers have given powerful evidence that I&M programs in general, whether centralized or decentralized, have hardly any smog-reduction benefits at all.[7] Anticipated inspection at certified stations, it turns out, is a wrong input for producing cleaner emissions from the fleet.

3. Government input strategies display very little ability to adapt to changing conditions. Unlike the free market, which is driven to discover new combinations of inputs to produce the outputs consumers desire, government procedures become locked in and very difficult to restructure or dismantle.

I&M programs have become part of "the establishment." Because Smog-Check is part of the status quo, it has become a focal point for discussion and planning. And as the status quo, it has created concentrated and well-organized interest groups that stand behind it, including both private I&M mechanics and entrepreneurs hoping to get contracts for new inspection facilities.

4. A program that specifies inputs inevitably entails large administrative and bureaucratic costs for managing the program and policing compliance. If those efforts are inadequate, corruption, fraud, and malfeasance may become widespread.

It is well known that corruption and fraud are common in decentralized programs; even centralized programs must monitor the diligence, competence, and honesty of the inspectors.[8] I&M programs must see to the training of licensed inspectors, the integrity of inspection equipment, the enforcement of honest inspection service, and the evaluation of program procedures. Corruption, fraud, and policing costs inevitably grow larger as government requirements reach deeper into the input stages of the production process.

5. The more programs are connected only indirectly to public-interest goals, the more likely it is that they will be hijacked and led astray. Influential special interests, including regulators, are tempted to favor their own convenience in deciding which inputs should be adopted to produce the public-interest outputs. When policies treat outputs directly, it is much more difficult for interest groups to cloud and usurp the issue.

Debates rage over the details of anticipated inspection. For example: Should anticipated inspection use dynamometers or less expensive equipment? If dynamometers, should they simulate a range of loads or only discrete loads? Should they report an emissions trace over the entire test, or should they report only peaks and averages? And so on. Every interest group takes its place in the political process and, in doing so, often obscures the fundamental issues. Politicized debates could be largely avoided if we had a strategy that dealt directly with outputs and was silent about inputs. The public interest would then be better recognized and better served.

Any technology for treating outputs must be reliably accurate, capable of measuring a range of emission constituents, and difficult for potential violators to circumvent. By those standards, remote sensing is not only a feasible technology; it is also generally superior to the regulatory I&M alternative widely mandated today.

Accuracy of Remote Sensing

Any kind of test system makes two types of errors. A false failure occurs when the system identifies a clean car as dirty. False failures cause motorists to incur costs unnecessarily. A false pass occurs when the system identifies a dirty car as clean; false passes are undesirable because high-emitting cars are not cleaned up.

It is well established that remote sensing takes a reasonably accurate snapshot of the CO and HC emissions from a car's tailpipe.[9] The snapshot is perhaps a little blurry, but it tells us whether we are seeing an antelope or a vulture. What is still debated is whether snapshots provide sufficient evidence, as opposed to a dynamometer's motionpicture footage of the car's exhaust over a few minutes. We argue that remote-sensing snapshots are in fact quite adequate. Motion-picture footage is, after all, just a series of snapshots.

A problem with emission snapshots is that they might capture the car's emissions performance at an uncharacteristic moment. A simple case is the cold start: during the few minutes it takes the engine to warm up, every car produces high emissions. Vehicle emissions also vary with speed, grade, load, and acceleration. If there were no way to control for those factors, the usefulness of remote sensing would indeed be doubtful.

But remote-sensing technicians can counteract those factors. Officials can select sites removed from residences and parking areas, to eliminate the cold-start problem, and find road features or use orange cones to put narrow bounds on the grade, speed, and acceleration variables. Remote sensing is most accurate when it reads cars under light acceleration, so a mild incline would be a benefit. If site selection is not enough to eradicate variation in driving modes, speed and acceleration can be measured using radar and cold starts can be detected with infrared cameras.

In one remote-sensing study, cars that had been read by a remote sensor were pulled over and given a regular smog test on the spot. Of the cars that had exceptionally high CO readings (above 4 percent), 91 percent failed the smog test.[10] Other studies have replicated that high correlation, and further developments would surely make the match even closer.[11] Snapshots and motion-picture footage tell the same story.

A report on California's Smog-Check program presents information on how likely it is that a remote sensor will wrongly identify a car as clean or dirty.[12] For a car in the set of clean vehicles, with "clean" defined as CO 4 percent or less of adjusted emissions, there is, on average, less than a 1 percent chance--0.64 percent, to be exact-- that it will exceed the 4 percent "cutpoint" at a single reading. For a car in the set of dirty vehicles, there is, on average, a 66 percent chance that it will not exceed the cutpoint at a single reading. If we have to go on merely a single snapshot, it seems that we have to accept a lot of false passes. Alternatively, we could reduce the false passes by lowering the cutpoint, but doing so would increase the false failures.

Fortunately, we do not face such a harsh trade-off. Instead of thinking of the remote-sensing errors of a single snapshot, we should consider the errors of systemwide multiple snapshots. Remote sensing is a remarkably inexpensive test--a conservative estimate is 75 cents per test--so we can multiply the remote sensors on the roads and use a pass/fail criterion based on a pattern of readings.

Consider, for example, a remote-sensing program for greater Los Angeles such that over a biennium the average number of readings for the entire fleet was eight. (Here we use summary figures for a scheme that is fully developed later.) Cars that traveled more than average would be read more than eight times, and cars that traveled less would be read fewer than eight times. Now suppose that we use a standard that fails a car if it exceeds the 4 percent CO cutpoint at least once over the entire biennium. A clean car, tested eight times, stands (on average) a 95 percent chance of never exceeding the cutpoint.[13] That is a 95 percent chance of remaining undisturbed, which, unless it be a new car, is 95 percent better than its prospects under the current program. A dirty car, read eight times, stands (on average) a mere 3.5 percent chance of not exceeding the cutpoint and getting away with a false pass over the course of the biennium.[14] Systemwide, the program produces few false failures and few false passes.

Remote sensing is a little less accurate at reading HC emissions than it is at reading CO emissions, but again the issue is not one of pin-point accuracy. As researchers at Resources for the Future have put it, "The remote-sensing [single-]test identification rate is not a critical determinant of the effectiveness of remote sensing--it is important only that super polluting vehicles can be identified by the test." [15] By increasing the cutpoint we can reduce the number of false failures, and by increasing the number of tests per year we can reduce the number of false passes.

The margin of error can be further reduced. The straight cutpoint criterion is in fact very crude. The system would accumulate a wealth of information, and more precise criteria could be developed. Consider the case of a salesman who travels all over Los Angeles in his clean car. He travels so much that his chance of exceeding the 4 percent CO mark during the biennium is greater than the 5 percent implied above. But for that motorist the system will have registered numerous clean readings, and on that basis a single dirty reading could be pardoned. Three clean readings might cancel a single dirty reading. Or the system could forgive first offenses or evaluate on the basis of running averages rather than cutpoint levels. It could blend the readings for the different pollutants into a composite variable. It could scan for engine behavior that alternates between running clean and running dirty (sometimes called "flipper" behavior). It could adjust for the measured speed and acceleration of the vehicle at the moment of emissions readings. It could take into account the age or model of the vehicle. And so on.

Outputs That Remote Sensing Does Not Measure

As shown above, policymakers can follow Adam Smith's advice and police CO and HC at the output stage. But CO and HC are not the only outputs we care about. Cars emit many other compounds, some of which are regulated and most of which are unregulated. One important regulated pollutant is nitrogen oxides (NO_x). Two manufacturers of remote-sensing equipment (Remote-Sensing Technologies Inc. and the Hughes Santa Barbara Research Center) have developed sensors capable of reading NO_x emissions. The accuracy is not as good as that for CO or even HC, but it is certainly good enough to detect high emissions of NO_x.

High emitters of NO_x emit more than 3,000 parts per million, and low emitters emit less than 1,000 ppm. Each of the two manufacturers reports that its NO_x readings, at least in prototype, are accurate with a standard deviation of 500 ppm. Hence the sensor should be capable of separating high and low emitters. [16] Both Remote-Sensing Technologies and Hughes now market remote sensors that measure all three pollutants, and they say accuracy will improve with further development.

A more fundamental question is whether being able to measure NO_x really adds much value to what we can accomplish with the ability to measure CO and HC. The answer appears to be yes. The automotive malfunctions that generate excessive NO_x emissions sometimes also produce excessive CO and HC emissions. Hence, to some extent, cracking down on the CO and HC culprits also means cracking down on the high NO_x polluters. For example, in a study conducted in Michigan in 1992, 37 vehicles with high on-road emissions of CO and HC were identified by remote sensors and recruited for repairs. [17] After repairs were made, the CO emissions declined by 95 percent, the HC emissions declined by 92 percent, and the NO_x emissions declined by 56 percent. Those results, although from a small sample, give some encouragement. However, most of the worst NO_x-emitting cars do not have high CO or HC readings. For that reason, we should plan on using remote sensing to read NO_x emissions, as well as CO and HC.

Another source of noxious outputs is evaporative HC emissions. Those occur, for example, when gasoline mixes with air in a carburetor, when the fuel line has a leak, or when the gas cap is missing. There is considerable debate over the magnitude of those emissions. One study claims that evaporative emissions account for over a third of the fleet's HC emissions, and the EPA has suggested the evaporative portion may be as high as one-half. [18] Those claims are based on laboratory tests of only a few vehicles and faulty estimates of the emissions inventory. [19] More recently, scientists at the Desert Research Institute studied the air in highway tunnels; subtracting the measured HC emissions coming from car tailpipes, they found that evaporative emissions account for less than 20 percent of HC emissions. [20] The tunnel studies do not consider, however, evaporative emissions that occur while a car sits parked with the engine turned off.

Evaporative emissions of the fleet are declining steadily as new engine technology replaces older technology, particularly the replacement of carburetors by fuel-injection systems. Evaporative emissions will decline further if fuel-

tank vapor-recovery systems come into use. It also is conjectured that a significant portion of evaporative emissions results from missing gas caps. A simple strategy for addressing the problem would be to broadcast television messages to inform viewers that not having a gas cap costs them gasoline, fouls the air, and creates dangerous slick spots when gasoline spills onto the road.

Remote sensing does not read evaporative emissions, but it might nevertheless help somewhat to reduce them because those emissions are correlated with tampering and inadequate maintenance, and those in turn are correlated with high emissions of CO, HC, and NO_x. Motorists who are induced to reduce their tailpipe emissions will make repairs that, in some cases, will also reduce nontailpipe emissions. Also, if cars flagged by remote sensing are required to report for follow-up inspection, follow-up procedures might include a visual inspection for sources of excessive evaporative emissions.

A final reason that the problem of evaporative emissions does not argue against a pure remote-sensing program is that, if the problem is a chink in the armor of remote sensing, it is a chink in the armor of any inspection system. Although the IM-240 protocol (the controversial, centralized auto I&M requirement for some regions stipulated in the 1992 Clean Air Act Amendments) includes tests for evaporative emissions, those tests are time-consuming and of questionable effectiveness. There is even concern that in performing the tests (known as the "pressure" and "purge" tests), technicians compromise the functioning of the emissions control system and consequently cause evaporative emissions to increase.[21]

Remote sensing, then, is not able to measure the full range of emission outputs that concern us, but its CO and HC capabilities cover most of the problem, and if NO_x capability is added, remote sensing will cover even more. The significant outputs not treated by remote sensing are relatively minor or are not treated in a cost-effective manner by any other inspection program.

Will Scofflaws Learn to Foil Remote Sensing?

One of the chief reasons for favoring an output-oriented policy is that, in leaving inputs unregulated, entrepreneurship is unleashed to the task of finding creative ways of producing what customers desire. There is one hazard, however. Strictly speaking, the output that a remote-sensing program sets for motorists is avoiding smog citations. It is possible that the process of entrepreneurial discovery will respond, not by cleaning up cars, but by foiling the system. Decentralized I&M programs are an object lesson in that hazard. A pure remote-sensing program will yield emission reductions only if human cunning cannot find convenient ways of foiling its efforts.

To thwart human ingenuity, a remote-sensing program should deploy a small number of on-road pull-over teams. If a car exhibits a suspicious feature, the computer will blow a whistle or illuminate a light, and the car can be stopped on the spot. Mere gross polluters would not be stopped; only those also suspected of subterfuge or rank noncompliance would be pulled over.

One method of foiling remote sensing is obstructing the license plate, for example, by splattering it with mud or putting a trailer hitch in front of it. That is a problem that could be easily policed by on-road pull-over. When the computer received information that a car had an illegible plate and high emissions, it would blow a whistle in real time and the car would be pulled over. Even without on-road forces, the problem could be combatted with elementary detective work using the video images of gross-polluting cars that have illegible license plates.

Another method of foiling the system is to keep the car unregistered so the program is not able to identify it and notify the motorist. That is a problem that is encountered by inspection programs of every kind. Again, the computer could be programmed to blow a whistle and the on-road forces could easily be used to nab unregistered vehicles. For various reasons, however, we may wish to restrict apprehension of unregistered vehicles to those that are also high emitters.

A third enforcement concern is the practice of evading remote-sensing sites. Such avoidance will be difficult for motorists because remote-sensing sites change by the day and are numerous and unannounced. One could imagine motorists with CB radios alerting their fellows, but it is hard to imagine that such evasive action would be consistently effective. Some people have suggested that radio stations might alert motorists to remote-sensing sites in their traffic

reports, but it is hard to believe that professional broadcasters would engage in such open subversion. Most radio listeners, after all, are law-abiding citizens who oppose gross polluting. An agency could infer the extent of evasion by comparing the rates of high emissions at normal remote-sensing sites with the rates at special stealth sites where motorists could not tell that their cars' emissions were being read. Also, the agency could gauge the problem of daily radio tip-off by comparing rates of high emissions during the first hour of operation at a site with the rate during later hours. If it found evidence of significant evasion, it could step up numerous tactics to mitigate evasion.

Another method of evasion might entail doing things to eliminate the exhaust plume as observed by the remote sensor, such as altering the tailpipe or turning off the engine as the car passed by a remote sensor. Those tactics are expensive or inconvenient. Again, the computer could flag cars for pull-over.

Finally, motorists might attempt to tamper with vehicles to alter the contents of the exhaust plume. That would require an additional gas source, to be mixed with the true exhaust, or perhaps an additive to the gasoline. More specifically, motorists might be able to foil remote sensors by making their cars emit excessive carbon dioxide (CO₂) emissions, because remote-sensing measures CO, HC, and NO_x each as a ratio to CO₂ emissions. Increasing the CO₂ content would therefore disguise gross emissions of the regulated pollutants. That kind of tampering represents the only serious threat to the remote-sensing program proposed in this paper. Whether it is a potent threat is unknown, but even if it is, program officials would employ their ingenuity in response, perhaps by devising a sensor for reading the absolute magnitude of CO₂.

It appears that scofflaw tactics pose no real threat to a program vested with on-road pull-over power. That power, even if exercised only seldom, would check subterfuge and go a long way in controlling the problem of unregistered high-emitting vehicles. The accumulated record of license-plate snapshots that are taken concurrently with remote-sensing measurements would supply incontrovertible evidence in prosecution. Whether the tactic of boosting CO₂ emissions poses a serious threat to remote-sensing operations is a question that deserves further investigation.

A Model Remote-Sensing Program

For a remote-sensing program to work optimally, it should include the following seven components:

- * on-road remote-sensing units
- * no periodic inspection
- * citation by mail
- * enforcement by division of motor vehicles and on-road pull-overs
- * early driver notification
- * repair subsidies for the poor
- * monetary fines

Each of those seven elements is discussed below.

On-Road Remote-Sensing Units

An effective remote-sensing program should have numerous remote-sensing teams deployed at random. They should not announce their siting plans and should pick sites to minimize evasion, congestion, and problems with getting valid readings. Legislation should attempt to simplify and ease the process of obtaining site permits from state, county, and municipal authorities.

No Periodic Inspection

A model program would deploy mobile remote-sensing units in adequate numbers to read cars an average of four to

eight times over the biennium. A basic question on everyone's mind is, should remote sensing merely supplement universal periodic inspection, or should it replace periodic inspection?

Earlier we likened remote-sensing readings to snapshots and I&M tests to motion-picture footage. From a practical standpoint, each approach gets the same picture. There are, however, two major differences between them. First, the cost of decentralized inspection and maintenance is about 60 times the cost of a single remote-sensing inspection.[22] If we say that on average cars should receive eight snapshot readings over the biennium, then decentralized I&M programs are still seven times as expensive as a biennium's worth of remote-sensing testing. Centralized inspections would probably be even more costly than decentralized inspections.[23]

Second, I&M motion-picture footage captures behavior that is like a performance on stage. Motorists can tamper with their vehicles before the inspection. In the case of remote sensing, the snapshots capture behavior that is unvarnished and true to life. Violators are caught in the act.

Defenders of periodic inspection say that remote sensing could discourage tampering between periodic inspections. That conclusion follows, but then we must ask what inspection adds to the surveillance achieved by remote sensing. If a bank had a video recording of a teller's actions and could easily scan it to determine whether he had sneaked into the vault, there would be no point in also interrogating him about his actions. With remote sensors supplying frequent and unanticipated inspection, periodic inspection becomes an expensive redundancy. It is the pony-express service that accompanies electronic mail.

Citation by Mail

A remote-sensing program should issue citations by mail to motorists with high-emitting vehicles. The citations would call for some kind of redeeming action within a given time period, say 21 days.

Some citations may not be properly received. One study reports that about 7 percent of vehicles in California are unregistered--a problem for any inspection program.[24] But the registration of a large number of those vehicles has merely lapsed a few months, so a citation would be properly received. Motorists who change residence and experience problems in receiving their mail should be treated no differently by a smog program than by a credit card company. People are held responsible for notifying others of their change of address and seeing that their mail is properly forwarded.

Another issue is popular and political acceptability. Sometimes the idea of smog citation by mail is likened to photo-radar speeding citation by mail (a practice that has been used in Pasadena and Folsom, California, and Pleasant Valley, Arizona). But comparing smog with speeding is problematic. Current speed limits are not analogous to "smog limits." Virtually all motorists exceed speed limits regularly, whereas only a small minority exceed smog limits. Many Americans feel that speed limits are too low and that enforcement is rather arbitrary. Indeed, traveling above the speed limit on a major highway may be safer than traveling at the limit, because speed variance is one cause of accidents.[25] In contrast, vehicle owners who received smog citations would be guilty of real and certain harm to society. As for the problem of "vicarious responsibility"--that is, the driver not being the owner--the problem is very minor in the case of smog: emissions do not depend on who is behind the wheel, unless the driver has very peculiar driving habits.[26]

One difference that makes smog citations less acceptable than speeding tickets is that motorists have a speedometer to tell them how fast they are going, but they do not have a "smogometer." High emitters might feel that it was unfair to penalize them for their ignorance. That problem, however, can be mitigated by public-access remote-sensing facilities, warning notices, and low initial fines. Furthermore, the emission limits actually enforced would be much higher than the legally enforceable limits--proportionally much higher than is the case for speeding enforcement-- so cited motorists would be on very shaky ground in claiming that their cars were within the legally enforceable limits.

A recent article finds that photo-radar programs are on firm ground both constitutionally and evidentiarily.[27] And researchers have surveyed citizens on their attitudes toward photo-radar citations for highway travel and found that 60 percent approve and 35 percent disapprove.[28] If researchers find that much juridical and popular support for photoradar, they are likely to find more support for remote-sensing smog citation.

Any public objection to remote sensing and citation by mail would be based mainly on a claim to privacy. Here the public must be made to recognize that remote sensing is a sort of social control mechanism, a mechanism to police good behavior, and that every type of social control mechanism-- whether it be the criminal justice system, the media, credit reporting, or gossip--necessarily collides with privacy in at least a small way. That remote sensing represents a serious invasion of privacy is doubtful. The roads are public property, and the government is the steward of the airshed. Checking discreetly whether individuals are abusing their access to those resources is not an "unreasonable search" or an intrusive act. A car's exhaust emissions are hardly a matter of personal intimacy, and it is unlikely that the mere act of monitoring emissions would give motorists a sense of being invaded.

In the interest of preserving individual privacy within the household, smog citations would not specify the exact time and place of readings. They should, for example, specify the week during which the reading was made and say nothing of the location. The exact information, including video images, could be made available upon request and used for dispute resolution.

Enforcement: Division of Motor Vehicles Records and On-Road Pull-Overs

There are two means of inducing compliance with smog citations. First, under current state law, the Department of Motor Vehicles can impose fines, deny vehicle registration, and impound vehicles that do not obtain the required smog certification.[29] In a remote-sensing program, drivers' licenses, vehicle titles, and registrations could be frozen until fines were paid.

Second, by virtue of automatic license-plate readers, on-road units could easily identify and pull over rank noncompliers and impound their vehicles. Thus, remote sensing is a means both of identifying gross polluters and of apprehending them. Current California law requires the Bureau of Automotive Repair and the Air Resources Board to institute an on-road enforcement program that may include remote sensing.[30] A record of remote-sensing violations and noncompliance would certainly supply probable cause. Other states also have laws that allow authorities to pull over "smoking" vehicles; the remote sensor is essentially a means of identifying "smoking vehicles," although the smoke may be invisible.

Pull-over forces would not stop the mere high emitter, the mere unregistered vehicle, the mere license-plate obscurer. They would pull over only the high emitters who were also unregistered, had illegible license plates, or had not complied with previous citations. Thus, only the hard-core minority of problem vehicles would be subjected to on-road pull-over.

Twenty-five pull-over teams, each working 260 days per year, seven hours per day, making three pull-overs per hour, would pull over 136,500 cars per year, or 1.6 percent of the vehicle population. Those would be the recalcitrant 1.6 percent who defied the law. Anyone who refused to comply with the program would face a large risk of pull-over.

The pull-over arm of a remote-sensing program should be separate from existing police forces. The program ought to create its own "smog squad" to enforce only emissions laws, just as parking patrols enforce only parking ordinances. If smog pull-over activities have to depend on conventional police resources, control over enforcement becomes spread over multiple agencies and coordination becomes difficult. It may be difficult and undesirable to divert the conventional police from their other duties. Smog enforcers would better perform their duties if they were specially trained and specialized in their activities.

Early Driver Notification

An important feature of a good remote-sensing program is notification of motorists whose cars are within smog limits but are approaching the limits or showing deterioration. The state would invest in a post card to notify motorists that they may wish to service their cars. The notification card would cite three good reasons for doing so: (1) helping to clean the air, (2) improving gas mileage, and (3) reducing the likelihood of being subject to future penalties. Early driver notification would be a positive service to motorists, as well as a sort of warning. It would prompt some people to reduce their emissions preemptively, before being compelled to do so.

Evidence of the power of early notification comes from a remote-sensing demonstration project conducted in Provo, Utah.[31] Over the course of several weeks, researchers monitored emissions at highway off-ramps. One group of motorists with gross-polluting vehicles was sent a friendly notice telling them that their cars were dirty and that they could take advantage of free repairs to get them cleaned up. Some motorists took advantage of the repair offer, but even the cars of the motorists who chose not to take advantage of the repair offer showed subsequent emissions reductions of 28 percent. Merely being alerted to the fact that one's car is a gross polluter can prompt one to clean it up. Part of the 28 percent reduction should be attributed to the natural tendency of motorists to clean up their dirty cars, but only part.

A control group of gross polluters was not sent any notices or invitations to repairs. High-emitting cars in that group showed the natural tendency toward reduced emissions to be only 14 percent. The difference between the reduction rates of 28 percent and 14 percent--that is, 14 percent of emission reduction--indicates the potential of purely voluntary notification. In a "fully armed" remote-sensing program, early notification would serve not only as a friendly notice but also as a warning.

The program should also extend a "notice of appreciation" to motorists with clean cars, perhaps after a series of readings has been compiled. That would reassure motorists of the cleanliness of their cars, and it would build goodwill with the public.

Repair Subsidies and Waivers

For reasons of enhanced compliance and political acceptability, it makes sense for the program to offer repair subsidies to the poor. Current California law, for instance, provides for a High-Polluter Repair or Removal Account to provide financial assistance to low-income people seeking to repair (up to \$450) or replace (up to \$850) their gross-polluting cars.[32] We favor a repair subsidy program but oppose "buy-back" or vehicle-retirement programs.

Any kind of subsidy program invites individuals to position themselves to be recipients. In a sense, a repair subsidy creates a demand for high-emitting vehicles, and individuals will meet that demand if the program does not include countervailing incentives. The following requirements ought to be built into the repair subsidy program:

- * Only repairs certified as necessary to rectify the car's high emissions are eligible. A car marginally exceeding its emissions standards is not eligible; instead it should be granted a waiver.
- * The car's emission system must show no signs of deliberate tampering.
- * The car must be registered.
- * The car owner must have a low income and few financial assets.
- * The car owner must pay a deductible, say \$75, on the total repair bill.
- * The car owner must make a copayment on the remaining amount of the bill, say 35 percent. For a total repair bill of \$450, therefore, the car owner would pay \$75 deductible + 35% of \$375 = \$206. The state would pay \$244.
- * No car owner could be the recipient of more than one repair subsidy for any one vehicle within a four-year period.

Funding for repair subsidies could come from general levies on car registration, program fees and fines, or corporate contributions to obtain pollution credits.

Buy-back programs are suspect because they are expensive (perhaps \$500 to \$800 per car) and because they tend to remove cars that are driven very little. After all, if you really rely on your car (and its roadworthiness), you probably will not sell it for a fraction of its replacement cost. With a buy-back program, an individual who is about to junk a car would have a strong incentive to put it into a condition that made it eligible for the buy-back program. The buy-back then is not really removing a dirty car from the road. With careful attention, the problems with buy-back programs can be reduced, but we should be reluctant to create an additional government program when remote sensing might treat

the problem more directly. The remote-sensing program would impel owners of high-polluting clunkers to clean them or retire them. Supplemental buy-back programs could perhaps be initiated by volunteer citizen efforts.

Waiver limits are the thresholds at which the repair bill is so high that the car is granted immunity from the program. With a repair subsidy program in place, waiver limits for gross polluters ought to be very high, or perhaps eliminated altogether. It is very rare that a car that has not been tampered with calls for more than \$800 in repairs to rectify its emissions. Under the repair program described here, the individual would pay \$329 of the bill. Even that amount may be a hefty tab for someone in poverty, but that is the rare, worst-case scenario.

Recommended System of Penalty: Monetary Fines

When a motorist receives a citation for exceeding the speed limit, driving recklessly, or parking illegally, he is required to pay a fine. A similar system of penalties could be used for smog violations. The alternative to a system of monetary fines would be a system that required cited motorists to report for follow-up inspection. The best system would use monetary fines and no follow-up inspection.

Social control mechanisms in general may have three goals: (1) compensation to those who suffered by the misconduct of wrongdoers; (2) protection of life or property (whether public or private) by deterrence, which is achieved by punishment of wrongdoers; and (3) correction (or rehabilitation) of the ways of wrongdoers.

The concrete objective of a remote-sensing program is the protection of the airshed from gross polluters. The airshed is the common property of the citizens, and the government acts on their behalf. Those who respect that property certainly ought not to be penalized for their good behavior (as they are by any variety of periodic inspection). But more to the point, it would be just to have those who damage the common property compensate those who have been harmed. Revenues from fines would go toward financing the program, which would benefit the community as a whole. Making gross polluters pay fines is one way of achieving community compensation and of giving the gross polluters a means of redeeming themselves with the community.

Monetary fines are at least as good a deterrent as is follow-up inspection. Like fines for speeding, fines for smog violations can be graduated according to the extent and consistency of the violation. They can give a mere slap on the wrist to those edging over the (actually enforced) limit and a stiffer smack to flagrant offenders. A program of monetary penalties will induce motorists to value and, if necessary, to seek in the marketplace their own prevention of such deterrence. In other words, motorists will be induced to keep their cars clean.

Finally, there is the issue of correction or rehabilitation. If the private individual, in his "local situation," values good advice on getting his car to pass muster with remote sensors, he will turn to the same sources that he turns to for his other needs, comforts, and pleasures-- namely, friends, family, neighbors, coworkers, and entrepreneurs in the private marketplace. The remote-sensing program will be creating market demand for prevention of smog citations. Under such a program, that good would be a normal private good like hamburgers or handkerchiefs; the free, private market would be best at producing and supplying it. Perhaps consumers would demand and mechanics would offer a warranty on smog repairs. Perhaps entrepreneurs would open up drive-through testing facilities that used remote sensing and charged just a few dollars. Such testing might become quicker and cheaper than going for a carwash.

Were the government to require follow-up inspection of dirty cars, it would be implementing precisely the command-and-control specification of inputs that we have criticized. The points raised earlier about the problems with specifying inputs--lack of local knowledge, chance of specifying the wrong inputs, lack of adaptation and experimentation, added administrative costs, and heightened politicization of the issue--all apply with force to follow-up inspection. Here it is appropriate to invoke the basic truth that capitalism works better than socialism.

Some people have wondered whether singling out the gross-polluting minority is fair. The answer is yes. Universal inspection and maintenance may superficially seem more equitable because everyone goes through a similar experience, but that is the sort of equality that a government achieves when it makes poverty universal. The goal of a good program must be to pursue the problem cases; it is no comfort to them to know that the others also have to undergo inspection and maintenance or other costly measures.

Another question is whether a system of monetary fines, as opposed to follow-up inspection, is inequitable. Some might dub monetary fines a payment for the right to pollute. We see no grounds for a charge of inequity. In a sense, in paying smog fines one does buy a right to pollute. By the same token, by paying speeding tickets one buys the right to speed. And, indeed, the rich are in a position to buy more of such rights. But if the rich decide to buy more polluting rights, that means that they have less wealth with which to lay claim to larger portions of the pie in other areas of life, such as food, housing, or entertainment. Thus, imposing monetary fines does not really favor the rich.

Consider the case of the rich playboy who tampers with his Porsche and figures that he will routinely pay the smog fines. The remedy would be, as it is for speeding violations, to escalate the monetary penalties for routine and flagrant offenses. The fines could be gradually increased until the wayward Porsche driver could expect to pay an extra few dollars for every trip he made.

Concern about the rich buying the right to pollute is unwarranted. The important point is that they be made to pay if they are polluting. Denying the opportunity to pay cash, and instead requiring follow-up inspection, may indeed make life harder for rich gross polluters, but, short of reveling in malice or envy, no one else will gain comfort from that requirement.

Another way to approach equity concerns is to ask specifically how the poor will fare. Indeed, monetary fines on the poor will smart and will induce them to clean up their cars. The system of warnings and gradually increasing fines will, however, give them ample opportunity to avoid the harsher fines. Monetary fines will hurt, but deterrence is a goal of the program. The deterrent power of both monetary fines and follow-up inspections is the punishment of wrongdoers, poor and rich alike.

One final point about equity: Equity is about the difference of conditions between groups, but not only income groups. There is also a distinction between those who comply and those who do not, between the innocent and the guilty. Concerns about equity and justice would seem to dictate that those groups be treated differently. Equity and justice would seem to suggest that the guilty compensate the innocent for their offenses, at least in an aggregate sense. The best way to do that is by monetary fines.

Program Costs and Revenue Projections

The ideal program would include pervasive remote sensing, on-road pull-over units, monetary penalties, and no follow-up inspection. Here we estimate the public-sector costs and revenues for a program for the greater Los Angeles area. The fleet consists of 8.5 million vehicles.[33] We will assume that the average number of times that a car's emissions are read by remote sensors per year is four. In other words, throughout this exercise we are assuming that each year the program makes 4×8.5 million (= 34 million) valid readings.

To establish the fullest possible range of estimates, every variable will be given three possible values: an optimistic value, an intermediate value, and a pessimistic value. The pessimistic case is really very pessimistic. Nevertheless, even after slanting cost assumptions against the program in every detail, we find that the program is inexpensive relative to the alternative--Smog-Check. A realistic estimate seems to lie somewhere between the optimistic and the intermediate values.

The variables, assigned values, and calculations are shown in Table 1. Lines 1 and 2 give estimates of the average number of deployment hours per day per remote-sensing device (RSD) and the average number of days of deployment per year. The remote sensor is technically capable of reading tailpipe emissions much more quickly than cars in fact pass by on the road, so the constraint in readings per hour is one of traffic flow. Estimates are based on experience in remote-sensing demonstrations.[34] The optimistic estimate is 650 readings per hour (or 1 every 5.5 seconds), the intermediate is 500 per hour (1 every 7.2 seconds), and the pessimistic is 400 per hour (1 every 9 seconds). The next line acknowledges that for technical reasons the system may not get a usable measurement and license-plate reading for every car. Along with estimates for other variables shown in the table, line 8 tells how many RSDs would be required to make an average of four readings per car in the fleet. Naturally, the optimistic column shows the lowest number of RSDs required.

The equipment needed for each on-road unit is listed and its costs estimated. Each unit would need a remote sensor

(including beams, sensors, and computer); a vehicle (presumably a van); an automatic license-plate reader; acceleration measurement equipment; and safety equipment. Estimates are based on a December 1992 survey of prices and market availability of such equipment and on consultation (August 1995) with Dennis Smith of Remote-Sensing Technologies Inc. and with Frank Huerta of Hughes Santa Barbara Research Center (those two firms sell most of the equipment).[35] Estimates of life span, maintenance costs, and insurance are also included. Line 21 gives total annualized cost of equipment for the program.

Table 1 Cost Estimate for a Pure Remote-Sensing Program for the Los Angeles Region			
	Optimistic Estimate	Intermediate Estimate	Pessimistic Estimate
Inspection Capability and Remote Sensor			
1 Hours of operation per day	10	8	7
2 Days per sensor per year	330	300	260
3 Hours per sensor per year	3,300	2,400	1,820
4 Gross readings per sensor per hour	650	500	400
5 Rate of valid readings	95%	88%	80%
6 Valid readings per hour	618	440	320
7 Valid readings per sensor per year	2,037,750	1,056,000	582,400
8 Number of sensors required for four valid readings per car per year	17	32	58
9 Total sensor hours per year	55,061	77,273	106,250
Equipment Costs per Remote Sensor			
10 Sensor (to read CO, HC, NOx) and computer	\$95,000	\$120,000	\$160,000
11 Vehicle with A/C, generator, etc.	\$26,000	\$35,000	\$40,000
12 Automatic license-plate reader with video equipment	\$16,000	\$20,000	\$30,000
13 Acceleration measurement equipment	\$4,000	\$5,000	\$9,000
14 Safety equipment	\$1,000	\$2,000	\$3,000
15 Subtotal, equipment costs	\$138,000	\$177,000	\$233,000
16 Annual maintenance and insurance rate on initial cost of equipment	0.15	0.25	0.35
17 Annual maintenance and insurance costs for equipment	\$20,700	\$44,250	\$81,550
18 Life of equipment (years)	6	4	2
19 Annualized purchase cost of equipment	\$23,000	\$44,250	\$116,500
20 Total annualized equipment, maintenance, and insurance cost per sensor	\$43,700	\$88,500	\$198,050
21 Total annualized equipment, maintenance, and insurance cost for all sensors	\$729,138	\$2,849,432	\$11,561,985
22 Number of employees per sensor	1	1.2	1.5
23 Cost per employee per hour	\$30	\$45	\$60

24 Employee time per hour of remote sensing	1.15	1.25	1.35
25 Total employee cost per hour of sensing operation	\$34.50	\$67.50	\$121.50
26 Total employee cost per year	\$1,899,595	\$5,215,909	\$12,909,375
Administrative Costs			
27 Annual cost of site selection	\$2,000,000	\$3,000,000	\$4,000,000
28 Correlation with DMV data	\$2,000,000	\$4,000,000	\$5,000,000
29 Program evaluation and refinement	\$2,000,000	\$3,000,000	\$4,000,000
30 Miscellaneous	\$2,000,000	\$3,000,000	\$4,000,000
31 Total annualized administrative costs	\$8,000,000	\$13,000,000	\$17,000,000
32 Cost per valid test	\$0.31	\$0.62	\$1.22
Citation Costs			
33 Cost of documentation, printing, and handling per notice	\$0.05	\$0.10	\$0.15
34 Total annual notification cost	\$4,717,500	\$5,355,000	\$5,992,500
35 Annual cost of pull-over activities	\$3,000,000	\$6,000,000	\$12,000,000
36 Total annualized program cost	\$18,346,233	\$32,420,341	\$59,463,860

Labor costs have three variables: number of employees required per RSD; hourly cost burden per employee (wage rate, benefits, Social Security taxes, workers' compensation, and the like); and employee job time per hour of RSD operation (there will be downtime while employees are in transit, setting up equipment, and so forth). Line 26 gives the estimates for total labor costs for the program.

Estimates of the cost per valid test, based on the assigned values for inspection capability, equipment cost, labor cost, and administrative overhead, are given in line 32. That calculation includes all costs that go into testing cars; it excludes the costs of citation and pull-over. Line 32 shows a cost-per-test range of from \$0.31 to \$1.22. The intermediate figure (\$0.62 per test) can be taken as a conservatively high estimate.

Costs of citation are also estimated. Line 33 gives estimates of the cost of documentation and printing each notice. For the total cost of notification, given in line 34, we figure that, on average, every car ought to be the subject of at least one notice per year, if only to report to the owner that the car is clean. Assuming also that some dirty cars receive multiple notices, each year the average number of notices received per car in the fleet is 1.5. Also going into the calculation of line 34 is a postage rate of 32 cents per notice.

Line 35 give estimates for the annual cost of on-road pull-over activity. A rough accounting for the intermediate value of \$6 million could be made as follows: 25 pull-over teams, each using three employees, each employee costing in total employment burden \$70,000, each team using equipment and vehicles with combined annualized cost of \$30,000. It is quite possible that pull-over activity would take advantage of on-site economies of scale by having one peace officer working with several technicians, as well as the on-site RSD operator. The site would require adequate room to pull over several vehicles at once.

Costs of Repair Subsidies

The costs of repair subsidies are given in Table 2. Those expenditures achieve something without analog in the cost calculations for Smog-Check presented below, so for purposes of comparison they have been kept separate from the other costs of the remote-sensing program. In the intermediate scenario of Table 2 we assume that 0.5 percent of the fleet will receive a repair subsidy. To qualify for a subsidy, the owner must have low-income status and his car must be high emitting, be registered, not have been tampered with, and not have benefited from a repair subsidy in the

previous four years. We assume that the average subsidy is \$250 (which corresponds to an average total repair bill of \$460 for cars receiving repair subsidies). Those assumptions yield total annual subsidies of \$10.6 million.

Table 2 Repair Subsidy Costs			
	Optimistic Estimate	Intermediate Estimate	Pessimistic Estimate
1 Number of cars receiving subsidy each year	21,250	42,500	85,000
2 Average value of subsidy	\$200	\$250	\$300
3 Total cost of subsidy	\$4,250,000	\$10,625,000	\$25,500,000

Remote Sensing vs. Inspection and Maintenance

The intermediate estimate of program's cost is \$32 million (Table 1). The per test cost of Smog-Check is given in Table 3.

Multiplying \$42.06 per test by an estimated 4.25 million Smog-Checks per year gives a total cost for the Los Angeles area Smog-Check program of \$179 million.[36] There is, however, one more significant cost of the current Smog-Check program that would be largely avoided in the remote-sensing program: the cost of unnecessary and even counter-productive repairs to marginal emitters. The Smog-Check program enforces a more stringent standard for all cars, even those that are basically clean but marginally over the limits. Marginal emitters undergo expensive repairs, even though we know that it is only the gross-polluting 10 or 20 percent that really matter. There is clear evidence that at least one-third of the cars that fail Smog-Check and are repaired enough to pass the test subsequently have higher emissions.[37] That is an enormous and totally useless cost of the current program, and it is a cost that would be largely avoided by the remote-sensing program. (It is, though, a cost that conventional Smog-Check could reduce by using more lenient emissions standards.) Taking the cost of superfluous repairs into account would heighten the contrast between the costs of the two programs.

Table 3 Cost of Smog-Check per Test	
Cost Component	Cost (\$)
Station cost	21.18
State cost	7.00
Motorist's time cost (a)	13.88
Total	42.06

*Source: California I/M Review Committee, pp. 94, 103.

(a) Motorist's time cost is based on an estimate of 83.25 minutes devoted to the chore of getting a car through the test, at a cost rate of \$10.00 per hour. The rate of \$10.00 per hour is probably an underestimate, since dealing with Smog-Check is an irregular and anxiety-filled task.

Total program costs--using the intermediate estimate for the remote-sensing program (excluding the cost of repair subsidies) and the very generous estimate for the Smog-Check program--are \$32 million for a remote-sensing program and \$179 million for Smog-Check. The cost of the current Smog-Check program is over five times that of the proposed remote-sensing program. The current program costs three times more than even the pessimistic estimate for remote sensing.

Remote sensing not only costs far less; it also promises to really make a difference in the quality of the air. A remote-sensing program makes unanticipated tests, and it tests each car, on average, eight times more often than does the current program. The ratio of cost-effectiveness between the two programs could well run in the hundreds.

Program Revenues

A remote-sensing program also would generate some revenues from smog fines. Line 1 of Table 4 gives the estimated average dollar amounts of smog fines. Line 2 gives estimates of the total number of fines levied, with the intermediate estimate corresponding to 6 percent of the fleet. Line 3 then gives estimates of the percentage of levies that are actually paid. The intermediate estimate of total revenues collected (Line 4) is \$15 million, an amount equal to 41 percent of the intermediate estimate of total program costs. In addition to the revenues from smog fines, there might also be revenues from the increase in the rate of vehicle registration, which would result from performing on-road pull-overs.

	High Estimate	Intermediate Estimate	Low Estimate
1 Average fine paid	\$50	\$35	\$20
2 Number of fines levied per year	1,020,000	510,000	85,000
3 Percentage of levied fines paid	95%	85%	75%
4 Total annual revenues from fines	\$48,450,000	\$15,172,500	\$1,275,000

An Inferior but Politically More Viable Penalty: Follow-Up Inspection

What is best is not necessarily appealing to those active in the political process. Fines might not be politically viable. For that reason smog violators could be required to report for some kind of scheduled follow-up inspection. That requirement would merely be a different kind of penalty; it would not contribute to the process of correction. Pervasive remote-sensor surveillance, with monetary fines and enforcement pull-overs, provides a penalty that generates the most efficient process of corrections: free and private enterprise responding to the needs of consumers. Inspection and maintenance simply change the penalty that causes the motorist to initiate that process. As a penalty, it is less efficient because it is expensive and basically redundant, given the pervasive deployment of remote sensors.

For follow-up inspection, the EPA favors use of the highly expensive dynamometer test (IM-240), which puts the car on a treadmill to simulate stop-and-go driving. The IM-240 reads CO, HC, and, NO_x emissions and gets a marginally better picture of a car's emissions than does the standard idle test (BAR-90) that is currently performed in California Smog-Checks.[38] BAR-90 does not read NO_x. The IM-240 test, however, uses more expensive equipment and more time per test.

There has been much controversy over test equipment; the regulators seem to have a penchant for high-tech approaches. The debates about the best test to perform at anticipated inspections have centered on the IM-240 and idle tests like the BAR-90. Yet the test that is really the most appropriate is neither; it is the remote sensor.

The best kind of anticipated inspection would work as follows: The cited motorist would bring his car to a designated inspection cite. There an employee would get behind the wheel and take the car on the official test route, which would probably be a test track but, in uncongested areas, might even be public roads. On the test route there would be three or four remote sensors. The car would pass by at different rates of acceleration or on different grades. The sensors would test for CO, HC, and NO_x. Since the car would be tested under carefully controlled conditions, the series of tests would give excellent results. Some kind of overhead covering, like those at gas stations, would have to keep rain off the pavement at the points where remote sensors measured emissions. Cars that had marginal or ambiguous results could be tested a second time. Cars that failed the test could be subjected to under-the-hood inspection.

Such a test program would do almost everything the IM-240 does. It would not make readings as accurately as the

IM-240, but it certainly would tell if the motorist had failed to make his car run clean. The basic goal of the program is the transformation of high emitters into low emitters. The differences that have been observed between the readings of IM-240 and those of remote sensors are insignificant.

The remote-sensing alternative is less expensive. Since only the cited minority of vehicles would be called to inspection, the stations would be few in number and located at out-of-the-way places where land is cheap. The main efficiency gain would come from the much higher throughput. Only those cars that failed the track test would need to be funnelled into inspection bays and attended to by technicians. Most of the labor would be low-skilled program drivers whose only qualification would be to be able to follow a two-minute driving pattern. Almost any high-school senior could learn to perform the job in a single day.

Another nice feature of a remote-sensing track for follow-up inspection is that, because the marginal cost is so low, the facility could sell its service to the public. Even motorists who have not been cited may wish to visit the track and pay \$3 to have their cars tested. Those motorists may wish to do so as a check against future smog citations, as a way of checking repairs that private mechanics have made to their cars, or simply out of environmental concern.

Combining Follow-Up Inspection with Monetary Penalties

The best system would be on-road remote sensing and monetary penalties. A compromise with the input-specification (i.e., command-and-control) modus operandi would be to penalize polluters by requiring follow-up inspection at remote-sensing tracks. Follow-up inspection might have more political currency than on-road remote sensing and fines, and there is a way of combining the two to get closer to the cost-effectiveness of the latter. Follow-up inspection could be merely one option for cited motorists. That would make the citation like a "fix-it" ticket, which would give the motorist the option of paying a fine or providing proof of having rectified the problem.

That is really a very neat solution. Motorists for whom reporting to follow-up inspection is highly costly would opt for paying in cash. That would be better for motorists and better for the state since it would gain revenues. Motorists with easier access to follow-up inspection or with limited funds could get their cars repaired. Follow-up inspection is significant only as a penalty, not as a corrective device. Whether motorists pay in cash or in kind, it is the constant threat of remote sensing on the roads that drives the corrections process.

A Program for the Near Term

The program laid out for the long term presupposes that remote sensing will prove to be a fully viable technology. A near-term proposal for the South Coast region of California is presented in this section. This proposal is less idealistic, more sensitive to political acceptability, and congruent with current legal guidelines.

Remote sensing is, however, still the major innovation. Enough remote-sensing capability should be deployed to yield an average of four valid readings per year for the entire fleet. Using the intermediate assumptions from Table 1, that would require 24 remote-sensing units.

The following three features of the long-term program already set out should be included in the near-term plan: citation by mail, on-road pull-overs of problem cars only, and repair subsidies for low-income motorists. The citations, however, would call cars to follow-up inspections rather than impose fines. Motorists would have to bring their cars either to a conventional I/M station or, if the state were required to build them, to centralized facilities.

Once remote sensing with pull-overs has been introduced, it makes little sense to continue calling all cars to biennial inspection. The vast majority of cars would have been subject to a remote-sensing test during the previous year. Hence, periodic inspection could be phased out. Recent state legislation that allows owners of new cars to buy out of their first Smog-Check has already begun the phase-out.[39] The process ought to be accelerated.

With remote-sensing forces on the road, we should call only a minority, say 15 percent, of the vehicle population to inspection. There are several possible criteria for selecting those 15 percent. One alternative would be random selection, so nobody felt picked on. As an alternative, it would be more effective in terms of emission reductions to select the model-year vehicles that are known to have the highest rates of excessive emissions; naturally that will strike

many as unfair. Third, we might wish to choose the cars that have not shown up on the remote-sensing monitors. No-shows would probably be cars that are driven infrequently, but the owners might have figured out ways to evade remote-sensing sites.

The state should resist all pressures to build centralized facilities. It makes sense to wait and see what remote sensing can achieve before sinking further investment into I/M operations.

Program Benefits

To evaluate the desirability of a program, we would like to get an idea of its cost-effectiveness, which is defined as its total benefits divided by its total costs. We have already described and estimated the total costs of a proposed remote-sensing program. What about its benefits? That question calls for some candid remarks.

How many drunk-driving accidents are prevented by the policing of drunk driving? In other words, how large are the benefits from the policing of drunk driving? We could count the number of drunk drivers apprehended during the year and figure that each time a drunk was prevented from making his journey the risk of accident was correspondingly reduced. That calculation would, however, greatly underestimate the benefits because it neglects the deterrent effect of the policing of drunk driving. The policing efforts remove not only the drunks who are apprehended but also the drunks who choose not to drive because they fear being apprehended. Because of the severe penalties for drunk driving, the deterrent effect of policing is probably far greater than the direct effect of apprehension. A researcher could hope to estimate the deterrent effect by studying the different rates of drunk-driving accidents in regions where the offense is strictly policed and regions where it is not. Even then, estimates of benefits would be very rough.

In the case of remote sensing, we cannot hope to estimate the deterrent effect until a program is in place. There is of course good reason to say that the deterrent effect would be "large," but how large is anybody's guess. There simply is no reliable procedure for estimating what human response will be in a setting that is entirely new.

We could hope to get a lower bound on program benefits by forecasting the direct-apprehension benefits and assuming the deterrent effect to be zero. In the case of remote sensing, direct apprehension is itself highly effective, much more so than for the policing of drunk driving. There are two reasons for that: (1) policing and surveillance with remote sensing are very inexpensive and pervasive, and (2) once a car is fixed it stays fixed for at least a while (whereas a man made sober can promptly make himself drunk again).

The vast majority of gross polluters would probably be read by remote sensor enough times in a year to receive a citation, since the average number of readings would be four per car. The cars that escaped detection would tend to be those that traveled little and hence polluted less. And the vast majority of motorists who received citations would probably clean up their cars, since leaving one's car dirty would leave oneself in constant jeopardy of penalty. We do not know how long a repaired car would remain low emitting, but we do know that repairs vastly reduce the emissions of high emitters, and we know that if the car resumed high emissions the system would probably detect it rather promptly.[40]

It seems reasonable to claim that, even with no deterrent effect, the remote-sensing program would probably eliminate the lion's share of the emissions from the high emitters. Since high and gross emitters generate about 88 percent of the on-road CO and HC, the direct reduction from the program would be perhaps 30 percent of total on-road fleet emissions. If the deterrent effect of the program were included, total on-road fleet emissions would probably be reduced by 50 percent. That claim is only an educated guess. ("On-road emissions" are only tailpipe emissions generated after a cold start.) One could estimate the corresponding emission reductions (in tons) and the corresponding cost-effectiveness of the program (in gram reduction per dollar), but doing so would give a false air of certainty to the figure. Suffice it to say that the benefits of the program would be huge, Angelinos would breathe much better air, and the cost-effectiveness of the program would be excellent--much better than that of any other program currently in operation or on the drawing board.

Beyond Inspection and Maintenance: Regulation Reconsidered

This paper has focused on I/M programs. We have argued that with remote sensing, periodic inspection is likely to

become largely redundant. In that event, it should be discontinued. But inspection and maintenance are just one sort of program aimed at reducing fleet emissions. Other programs include carpooling mandates, emissions requirements on new cars, zero-emission vehicle quotas, and alternative fuel mandates.

Our reasoning applies to those other programs as well. As an air quality measure, carpooling mandates, such as Los Angeles's Regulation XV or the EPA's ECO plan, are gravely ill considered. They are extreme examples of input-oriented strategies that fail to go to the heart of the problem yet impose enormous costs. Recent literature shows convincingly that those programs rate terribly in cost-effectiveness.[41]

Smog is a problem only in certain regions, yet the EPA's new-car emission standards mean that many car buyers have to pay more for a new car even though they are not living in an area with a smog problem. If possible, the smog problem ought to be addressed by regional, decentralized programs. Remote sensing promises to do that. Again, the success of remote sensing should lead us to reconsider basic policy.

With functioning remote-sensing programs, regions can police emissions and thereby induce automakers and the energy industry to serve the new demand for clean cars. Motorists will demand clean cars to pass muster with the remote sensors. Again it is a matter of seeing the problem in the manner of Adam Smith. Let local regions police emission outputs as they deem necessary, and leave the inputs free to find the most efficient methods of meeting those output requirements. Those methods might include alternative fuels and certainly will include low-emitting vehicles, but in the free-market system the methods are selected by the competitive forces of the market, which does better than government agencies.

Conclusion

Remote sensing is not a fully proven technology. But the data look promising, and we should look ahead at the full implications of a viable remote-sensing technology.

If remote sensing lives up to its promises, the best way to control auto emissions is a remote-sensing program that punishes persistent high emitters with monetary fines. The program simply polices the airshed, which is common property. Protecting the common property with remote sensors should be understood as analogous to the owners of a bank protecting their common property by setting up video cameras in the bank lobby to watch for thievery. Like the bank video cameras, remote-sensing polices the outputs--what we really care about--rather than plans the inputs. When outputs can be effectively policed by government, it is best to leave the inputs free to dance their own steps within the market framework to meet the output demands set by government.

This market-based approach stands in sharp contrast to elaborate and costly schemes for reducing auto emissions. State automobile I/M mandates, mandatory carpooling, emission requirements on new cars, alternative fuel schemes, and the like are all attempts to reach back into the production process and specify inputs. Adam Smith described the fallacy of that modus operandi:

The man of system . . . is often so enamored with the supposed beauty of his own ideal plan of government that he cannot suffer the smallest deviation from any part of it. He goes on to establish it completely and in all its parts, without any regard either to the great interests or to the strong prejudices which may oppose it; he seems to imagine that he can arrange the different members of a great society with as much ease as the hand arranges the different pieces upon a chess board; he does not consider that . . . in the great chess board of human society, every single piece has a principle of motion of its own altogether different from that which the legislature might choose to impress upon it.[42]

If we continue to promote programs that neglect our new-found hope of treating directly the output in question, and instead command and control the behavior of others to serve a favorite input scheme, then we fail to take into proper consideration the teachings of Adam Smith. But if instead the Smithian principles are applied to auto emissions, society will be less bureaucratic and the air will be cleaner.

Notes

[1] Douglas R. Lawson, "Costs of 'M' in I&M--Reflections on Inspection/Maintenance Programs," *Journal of the Air & Waste Management Association* 45 (June 1995): 465-76.

[2] Douglas R. Lawson, "Passing the Test--Human Behavior and California's Smog Check Program," *Journal of the Air & Waste Management Association* 43 (December 1993); and Amihai Glazer, Daniel B. Klein, and Charles Lave, "Clean on Paper, Dirty on the Road: Troubles with California's Smog Check," *Journal of Transport Economics and Policy* 29 (January 1995): 85-92.

[3] "EPA Gives Go Ahead on Flexibility Measures for State Vehicle Smog Check Programs," EPA E-mail news release, September 7, 1995.

[4] Adam Smith, *The Wealth of Nations* (1776), ed. Edwin Cannan (New York: Modern Library, 1937), p. 681.

[5] *Ibid.*, p. 423.

[6] California I/M Review Committee, "Evaluation of the California Smog Check Program and Recommendations for Program Improvements," Fourth report, February 16, 1993, p. 10; and Environmental Protection Agency, "EPA Responses to Questions," Prepared for the joint public meeting of the California I/M Review Committee, California Air Resources Board, and Bureau of Automotive Repair, July 29, 1992.

[7] Lawson, "Costs of 'M' in I&M"; and Huel C. Scherrer and David B. Kittelson, "I/M Effectiveness as Directly Measured by Ambient CO Data," SAE Technical Paper Series 940302, 1994.

[8] On fraud and corruption, see Glazer, Klein, and Lave, "Clean on Paper."

[9] Douglas R. Lawson et al., "Emissions from In-Use Motor Vehicles in Los Angeles: A Pilot Study of Remote Sensing and the Inspection and Maintenance Program," *Journal of the Air & Waste Management Association* 40 (1990); and Lowell L. Ashbaugh et al., "On-Road Remote Sensing of Carbon Monoxide and Hydrocarbon Emissions during Several Vehicle Operating Conditions," in *PM10 Standards and Nontraditional Particulate Source Controls*, ed. J. C. Chow and D. M. Ono (Pittsburgh: Air & Waste Management Association, 1992), vol. 2, pp. 885-98.

[10] Lawson et al.

[11] Among the other studies is Ashbaugh et al.

[12] California I/M Review Committee, p. 129.

[13] We should further recognize that, of the cars in the set defined as "clean," it will be the relatively dirty ones that tend to fail.

[14] It will be the relatively less dirty cars that tend to sneak by.

[15] See "Conclusions" of "Overview of RFF Analysis of Remote Sensing," Presentation by Resources for the Future, April 1993.

[16] NO_x sensing will most faithfully distinguish dirty cars from clean when the cars are under load; hence the NO_x sensor will work best when used on uphill grades.

[17] Robert D. Stephens et al., "The Michigan Remote Sensing Study: A Preliminary Review of Repair Induced Emissions Reductions," General Motors Corporation, 1993.

[18] California I/M Review Committee, p. 97; and EPA Guidelines, *Federal Register* 57, no. 215 (November 5, 1992).

[19] See Douglas R. Lawson, letter to Richard J. Sommerville, November 6, 1992.

[20] A. W. Gertler et al., "Apportionment of VOC Tailpipe vs. Running and Resting Losses in Tuscarora and Fort

McHenry Tunnels," Paper presented at the EPA/A&WMA International Conference on the Emission Inventory: Perception and Reality, Pasadena, California, October 1993.

[21] D. J. Brooks et al., "Real World Hot Soak Evaporative Emissions--A Pilot Study," Society of Automotive Engineers Technical Paper 951007, March 1995.

[22] This ratio is based on the Intermediate estimate of the remote-sensing cost per test (line 32 of Table 1) and the \$42 estimate for the cost of a Smog-Check. The cost per remote-sensing test used here excludes the costs of citation, pull-overs, and repair subsidies.

[23] That centralized inspection has a higher total social cost per test than decentralized Smog-Check is disputed by the California I/M Review Committee and some EPA officials. See Eugene J. Tierney, "I/M Network Type: Effects on Emission Reductions, Costs, and Convenience," EPA Document EPA- AA-TSS-IM-I/M-89-2, January 1991, pp. 45, 46. For a treatment that counters the claim made by the California I/M Review Committee, see Amihai Glazer, Daniel B. Klein, and Charles Lave, "Clean for a Day: Troubles with California's Smog Check," University of California Transportation Center Working Paper no. 163, August 1993, pp. 21-25.

[24] California I/M Review Committee, p. 124.

[25] See Charles Lave, "Speeding, Coordination, and the 55 M.P.H Limit," American Economic Review 75, no. 5 (December 1985): 1159-64.

[26] Sierra Research hired a professional race-car driver to show that emissions from a clean car could be made to look dirty to remote sensing. That demonstration scarcely poses a challenge to the remote-sensing agenda, because remotesensing sites would be chosen for appropriate conditions, and because the program measures speed and acceleration of the car. See Thomas C. Austin, Francis J. Di Genova, and Thomas R. Carlson, "Analysis of the Effectiveness and Cost-Effectiveness of Remote Sensing Devices," Report prepared by Sierra Research for the Environmental Protection Agency, May 18, 1994.

[27] Janice V. Alcee et al., "Legal Issues Concerning the Use of Photo-Radar," Transportation Research Record 1375 (1992): 17-25.

[28] Cheryl W. Lynn, Wayne S. Ferguson, and Nicholas J. Garber, "Feasibility of Photo-Radar for Traffic Speed Enforcement in Virginia," Transportation Research Record 1375 (1992): 11-16.

[29] California Health and Safety Code (1994), sec. 44081.

[30] California Health and Safety Code (1994), secs. 44081- 44095.

[31] Gary A. Bishop et al., "A Cost-Effectiveness Study of Carbon Monoxide Emissions Reduction Utilizing Remote Sensing," Journal of the Air & Waste Management Association 43 (1993): 978-88.

[32] California Health and Safety Code (1994), secs. 44090- 44095.

[33] This figure is based on 7.9 million registered vehicles; that figure is adjusted for the 7 percent of the fleet that is unregistered. California I/M Review Committee, pp. 74, 124.

[34] During a four-day remote-sensing study in Baton Rouge, 24,000 readings were taken by two remote sensors. Assuming eight-hour days, that translates into 375 readings per hour, or one reading every 9.6 seconds. See Babak Naghavi and Peter R. Stopher, "Remote Sensing, Means, Medians, and Extreme Values: Some Implications for Reducing Automobile Emissions," Transportation Research Board preprint, 1993, p. 8.

[35] The survey is Hughes Environmental Systems, Inc., "Feasibility Study for the Use of Remote Sensors to Detect High Emitting Vehicles," December 22, 1992, pp. 5.13, 3.4 through 3.6. Prepared for South Coast Air Quality Management District.

[36] There are some minor factors to consider in this asumption. We are supposing that there are 8.5 million SmogChecks every biennium, even though there are only 7.9 million registered vehicles at any one time. However, many registrations have merely lapsed a couple of months. And cars must pass through Smog-Check not only on a scheduled biennial basis but also whenever they change ownership. On the other hand, a new law allows owners of new cars to buy out of their first Smog-Check.

[37] Lawson, "Costs of `M' in I&M."

[38] Ibid.

[39] California Health and Safety Code (1994) secs. 44090- 44095.

[40] On reduction of emissions, see Lawson, "Costs of 'M' in I&M."

[41] Kenneth C. Orski, "Evaluation of Employee Trip Reduction Programs Based on California's Experience with Rule 1501, An Informal Report of the Institute of Transportation Engineers," Resource Papers for the 1994 ITE International Conference, January 1994.

[42] Adam Smith, *The Theory of Moral Sentiments* (6th ed., 1790), ed. D. D. Raphael and A. L. Macfie (New York: Oxford University Press, 1976), pp. 233-34.