Sulfur Emissions From Diesel Engines

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1 Introduction

In the 1970s, the US succeeded in almost eliminating lead from the gasoline supply. Now, the US EPA has enacted regulations to similarly reduce sulfur levels in diesel fuel. Yet, its plan for doing so has been challenged as unachievable by various industry groups (eg. [MBT2001]). This paper will discuss the costs and benefits of reducing sulfur emissions from diesel engines, and examine market-based policies to achieve the desired reduction in an efficient way.

2 Relevant Externalities

The externalities causing inefficiently high sulfur emissions from diesel engines can be grouped into two categories. The first category is the harmful effects of air pollution; the second is the subsidies to activities that use diesel fuel, especially driving, trucking, and farming.

2.1 Air Pollution

Air pollution externalities from sulfur in diesel fuel fall into two main groups: health effects, and other effects.

The main health effects from diesel fuel comes from particulates. When inhaled, particulates remain in the lungs, and are responsible for "elevated rates of asthma attacks, lung disease, heart disease, cancer and even premature death"[NRDC]. Sulfates (SO_4) are the particulates primarily responsible for these health effects [Burtaw1997]. These health effects are externalities because they are not primarily borne by the emitters; instead they are borne by bystanders, both locally and in other regions, and the emitters do not fully account for these costs when deciding how much to use their diesel engines. Thus marginal social costs are greater than the marginal private costs to the emitter.

There are several other negative externalities related to the sulfur in diesel fuel. Acid rain is caused when sulphur dioxide (SO_2) and nitrogen oxide (NO_X) combine with atmospheric water. This rain causes damages to lakes, forests, crops, and human structures, and most of the resulting costs are borne by people other than the emitters. Sulfates and other particulates also reduce visibility and cause buildings to become dirty at a faster rate, again creating costs of which the emitters see only a small part. Finally, sulfur is partly responsible for the odor of diesel engines, which creates high costs for others[Tietenberg2003].

2.2 Subsidies

Any subsidy to diesel use would result in an inefficiently high level of diesel emissions. The marginal private costs would be lower than the marginal social costs (if the subsidy is considered to lower private costs and increase social costs), creating an externality. There are two main uses of diesel engines that are subsidized: driving, especially long-distance trucking, and farming crops.

The subsidies to driving are numerous [Tietenberg2003]. Road construction and maintenance are funded by taxes. Parking is funded by taxes in the case of street parking, and by employers. Arguably, the cost of traffic enforcement is a subsidy to driving. The effect of these subsidies on trucking is exacerbated by the comparative lack of subsidies for other forms of goods transport such as rail. Other negative externalities generated by driving include accidents and congestion; these are not subsidies, but they also inefficiently raise the amount of driving.

Farm subsidies also constitute another major source of subsidies to diesel use. There are direct subsidies to farm-related diesel consumption, in the form of tax exemptions on red-dyed (farm purpose) diesel fuel. The other subsidies to farming itself (such as price supports and quota systems) result in higher than efficient levels of farm activities, which include the use of diesel engines.

3 Measuring Benefits

Measuring the benefits of reducing sulfur emissions from diesel engines is largely a matter of measuring the damages caused by the emissions. As stated above, these damages can be grouped as health damages and other damages.

3.1 Health damages

Health effects of sulfur in diesel fuel can be modeled in two ways: intrinsically, using knowledge of the effects of particulates on human physiology, and extrinsically, using epidemiological studies to relate increased particulate pollution to population health outcomes. These health effects can be translated using two different measures. First, a statistically expected increase in the number of deaths due to sulfur particulates can be calculated. The value of a statistical life can be estimated, for example, by examining how risk-taking is compensated by increased wages in the labour market. Combining the two gives a dollar value for the deaths caused by this pollution. The second measure involves translating the adverse health outcomes, including not only mortality but also morbidity, into quality adjusted life years lost. These are often expressed in dollar terms using contingent-valuation or survey methods.

The first method is the one generally used to determine health costs due to particulate pollution. Arguably, this may overstate health costs. Estimates of the value of a statistical life are taken mostly from men in their prime, whereas the elderly, the sick and the very young are most susceptible to health effects from particulate pollution. Estimates of the values of the statistical lives of the elderly are often somewhat lower than those of the non-elderly. On the other hand, labour market studies involve voluntary risk taking, whereas the risks of pollution are largely involuntary (this being the source of the externality). It may be that these involuntary risks should be compensated more highly.[Burtaw1997]

3.2 Other damages

There are a number of other important damages caused by acid rain.

First, visibility is reduced. The value of this visibility may be estimated with contingent valuation methods, measuring willingness to pay for use and non-use values [Burtaw1997]. It may also be estimated with hedonic pricing of visibility as a component of real estate prices. Another way to measure it is to distinguish between recreation facilities with different visibility, and compare travel costs.

Second, recreational lake fishing is reduced. The magnitude of this cost can be estimated in two ways. The travel costs could be studied, including how travel would change based on a different fish-caught-per-unit-effort. This would indicate the lost benefits of fishing. Alternatively, the cost of liming the lakes to restore the acid balance could be computed.[Burtaw1997] Other reductions in recreation value could be measured with travel cost methods.

Third, agriculture and commercial forestry would be reduced. These costs could be estimated by looking at the profit lost because of the reduction in harvested crops due to acid rain[Burtaw1997].

Other effects include aesthetic, option values and non-use values for the affected ecosystems. It is more difficult to assign a cost to these; it is often done with contingent valuation methods.

3.3 Effects on other pollutants

A particularly tricky damage cost to measure is the effect of the sulfur content of diesel on other diesel emissions. Catylized diesel particulate filters and diesel oxidation catalysts, which the EPA believes to be the appropriate technology for future diesel emission reductions, are poisoned by sulfur. These technologies can not be brought to market without low-sulfur diesel[EPA2000]. If the benefits of the enabled reductions of other pollutants are to be counted as benefits of sulfur reductions, it would be appropriate to count the net benefits, not the gross benefits.

4 Measuring Costs

The costs of reducing sulfur emissions from diesel engines depend on how those reductions are obtained. There are three possibilities: reducing the sulfur content of diesel fuel, reducing the amount of diesel fuel used, and installing equipment to reduce the sulfur content of the engine emissions.

4.1 Reducing sulfur content of diesel fuel

The costs of reducing the sulfur content of diesel fuel are usually estimated by considering the best technologies available to refineries for achieving this reduction. In some cases, technology is considered that is not yet available; this is the case for the technology proposed by the EPA for measuring the sulfur content of ultra-low-sulfur diesel fuel [DOE2001]. This arguably understates costs. Considering the different marginal costs of reducing sulfur levels to each refinery, a supply curve can be constructed. Matched with a demand curve, this leads to estimates of increased costs per gallon and increased total costs for low sulfur fuel. [EPA2000]

Of course, one can also look at the additional cost of ultra-low-sulfur diesel fuel that is already available in California and other markets, as a first estimate.

4.2 Reducing fuel usage

One obvious method of reducing diesel fuel use is to reduce the subsidies to its use. This would not increase total costs, but would rather shift costs from society to the users of diesel fuel. It may even lower total costs, as the fuel users reduced their fuel use to account for higher private costs. However, if this did not produce the desired reduction in fuel use, it is possible to impose further costs on diesel fuel users. This could be done either with taxes (on fuel, emissions, driving, vehicle weight, or a combination), or with a quantity-based permit scheme. To the extent that these costs exceed the marginal social costs of the diesel fuel use, they result in a deadweight loss, which may properly be counted as a cost.

Another method of reducing diesel fuel use is to set standards for fuel economy, such as the CAFE standards set for gasoline engines in the US. The primary cost of such a program is the increased cost of efficient engines. These increased costs can be estimated in numerous ways. An engineering approach would examine the modifications in engine construction processes to project increased costs. Expert estimates (the so-called Delphi method) could also be used, though these would likely incorporate some aspects of an engineering approach. Another method is to price the additional parts required for each engine. This final method may underestimate costs, but is less uncertain.[Kling1994] Fuel economy standards may have other, unexpected costs as well. For instance, lower fuel consumption costs (which are marginal costs of driving) may increase the amount of driving, increasing congestion. Combined with the increased weight of more efficient engines, this may increase the frequency and severity of automobile accidents.[Harrington2001]

4.3 Using control equipment

There is currently no available technology that can effectively reduce sulfur emissions from diesel engines. Sulfur interferes with, and rapidly reduces the effectiveness of, all existing technologies for reducing diesel engine emissions[NRDC]. Indeed, this is the primary reason for the EPA's ultra-low-sulfur diesel regulations. However, if there were such technology available, it would likely increase vehicle costs. These costs could be estimated as described above for the costs of more efficient engines.

This control equipment would also have to be inspected and maintained over the life of the vehicle. This would generate costs, notably the costs of inspection and of making the necessary repairs, as well as opportunity costs for the time used in doing so.

5 Evidence on Benefits and Costs

5.1 Benefits

There are two main sources of benefits from the reduction of sulfur emissions: health costs, and other costs.

The EPA has projected health benefits for a reduction in the sulfur content of diesel fuel to 15ppm (so-called ultra-low-sulfur diesel), and the associated reduction in other emissions made possible by the lower sulfur content. These comprise "the yearly avoidance of: approximately 8,300 premature deaths, approximately 5,500 cases of chronic bronchitis, roughly 361,400 asthma attacks, and significant numbers of hospital visits, lost work days, and multiple respiratory ailments (including those that affect children)."[EPA2000] By 2030, the annual monetized benefit of this reduction in health costs is expected to be $62 billion.[EPA2000] This is driven primarily by the value of the expected deaths. Elsewhere, it has been estimated that 89% of the health benefits of acid rain reduction (mostly from coal plants) are attributable to reduced SO_2 emission [Burtaw1997]. If this holds true for diesel emissions, this would result in approximately $55 billion in health benefits due to sulfur reductions alone.

Other estimated benefits for the EPA's proposed sulfur reduction include "welfare benefits related to the reduction of agricultural crop damage, impacts on forest productivity, visibility, and nitrogen deposition in rivers and lakes."[EPA2000] These benefits are estimated to total approximately $7.75 billion annually by 2030 [EPA2000]. They are significant, but an order of magnitude less than the health benefits.

These numbers are for the planned reduction of sulfur content of diesel fuel to 15ppm. However, there are no important thresholds for sulfur reduction with respect to health costs. Mortality costs increase across all levels of emissions

[Burtaw1997]. Therefore, lower or higher reductions can be expected to produce correspondingly lower or higher health benefits.

For comparison, the annual benefits in 2010 for the Clean Air Act amendments of 1990 (which are largely attributable to reductions in sulfur emissions [Burtaw1997]) have been estimated as follows. Mortality benefits are estimated at $59.29 per capita for the affected population (1990 dollars); morbidity benefits at $3.50; visibility benefits (residential and recreational combined) at $9.15; and aquatic damage reduction at $0.62.

5.2 Costs

As described in section 4, the two main sources of costs of reducing sulfur emissions from diesel engines are the costs of reducing the sulfur content of diesel fuel, and the costs of controlling engine emissions.

5.2.1 Reducing sulfur content of diesel fuel

The cost of reducing the sulfur content of diesel fuel to 15ppm has been widely estimated to be about 5 cents per gallon. The EPA impact report states:

> We estimate that the overall net cost associated with producing and distributing 15 ppm diesel fuel, when those costs are allocated to all gallons of highway diesel fuel, will be approximately 5.0 cents per gallon in the long term, or an annual cost of roughly $2.2 billion per year once the program is fully effective starting in 2010. [...] This cost consists of a number of components associated with refining and distributing the new fuel. The majority of the cost is related to refining. From 2006-2010, refining costs are estimated to be approximately 3.3 cents per gallon of highway diesel fuel, increasing to 4.3 cents per gallon once the program is fully in place. In annual terms, the 2006-2010 refining costs are expected to be about $1.4 billion per year, increasing to about $1.8 billion in 2010. [...] A small cost of 0.2 cents per gallon is associated with an anticipated increase in the use of additives to maintain fuel lubricity. Also, distribution costs are projected to increase by 1.0 cents per gallon during the initial years under the temporary compliance option, including the cost of distributing slightly greater volumes of fuel. Together, these two cost components only amount to about $0.5 billion per year beginning in 2006. These costs drop to only about $0.3 billion in 2011 when the temporary compliance option and hardship provisions are over. [EPA2000]

The US Department of Energy has similar estimates. Without accounting for the sulfur trading provisions allowed by the regulations, the DOE estimated initial costs of producing ultra-low-sulfur diesel fuel to be 2.5 cents per gallon for the lowest cost supplier. But upon examining all suppliers' costs and constructing supply and demand curves, the estimates of marginal costs rose to 5.4

to 6.8 cents per gallon at the volume required [DOE2001]. This is subject to considerable uncertainty, due to the possible inability of many refineries to meet the standards. Mid-term costs were estimated to be slightly higher, at 6.5 to 7.2 cents per gallon.

Other estimates put refinery costs at 4.0 to 10.7 cents per gallon [EPA2000]. European estimates for similar reductions range from 4 to 13 cents per gallon [NRDC].

These estimates can be compared to current costs of ultra-low-sulfur diesel fuel. Shortly after California announced its ultra-low-sulfur diesel regulations, ARCO began selling ultra-low-sulfur diesel at a 5 cent per gallon premium to regular diesel [GDTV].

Offsetting these costs are certain cost reductions. The EPA impact analysis claims, "Operation with 15 parts per million sulfur diesel fuel is expected to reduce average vehicle maintenance costs by approximately 1 cent [per gallon]. Beginning in 2011, this reduction in maintenance costs will total roughly $400 million per year. "[EPA2000]

All these costs are estimated based on implementing the EPA regulations, particularly with a fairly abrupt phase-in of ultra-low-sulphur diesel. The DOE has estimated that a smoother phase-in could save $20 billion over 10 years[Oak2000]. Partly this is due to the present unavailability of all the necessary technology to achieve and measure these reductions. It has been suggested by industry groups that slightly more lenient standards of 50ppm would result in much lower costs. However, engine manufacturers are pressing for more stringent standards of 10ppm to allow their emissions control technology to meet other regulated emissions reductions.

There is some limited sulfur trading among refineries permitted by the EPA's regulations [Harrington2001]. Further trading could decrease costs. When lead was phased out of the gasoline supply, the trading component of the program is estimated to have saved $226 million of the control costs[Harrington2001]. Empirical modeling work has shown that hydrocarbon trading and fleet-wide averaging would lead to between 9 and 14 per cent reductions in control costs [Kling1994]. So it is reasonable to predict that more flexible trading schemes in the ultra-low-sulfur diesel regulations would reduce costs somewhat as well.

5.2.2 Vehicle emission control costs

There is currently no technology to effectively reduce diesel engine emissions (including sulfates and other particulates) in the presence of large amounts of sulfur. It is difficult to predict the cost of this technology if it were to become available. However, it may be reasonable to assume that it is on the same order of magnitude as the currently available technology.

For its proposed diesel emission reduction technology, the US EPA estimates that

> For light heavy-duty vehicles, the cost of an engine is estimated to increase by $1,990 in the early years of the program reducing to $1,170

> in later years and operating costs over a full life-cycle to increase by approximately $600. For medium heavy-duty vehicles the cost of a new engine is estimated to increase by $2,560 initially decreasing to $1,410 in later years with life-cycle operating costs increasing by approximately $1,200. Similarly, for heavy heavy-duty engines, the vehicle cost in the first year is expected to increase by $3,230 decreasing to $1,870 in later years. Estimated additional life-cycle operating costs for heavy heavy-duty engines are approximately $4,600. [EPA2000]

These costs include approximately $605 million in R&D costs [EPA2000]. However, these technologies are predicted to save $610 of maintenance costs over the lifetime of a heavy truck or bus, because of reduced engine corrosion and acidification of engine oil [NRDC].

By comparison, current gasoline emission controls lead to per-vehicle consumer costs estimated at between $337 and $1161[Kling1994].

Note that the total projected costs of even the EPA program, which has only limited market-based elements, is an order of magnitude less than the health benefits alone.

6 Potential Market-Based Control Policies

Market-based control policies targeting sulfur emissions from diesel engines can target two different stages: the manufacture of diesel fuel and engines, and their use by consumers. Policies concerned with manufacturing will have lower transactions costs, because of the lower number, greater size, and lesser diversity of manufacturers compared to consumers [Harrington2001]. However, policies concerned with the use of engines and fuel may have more lasting impact, because of the crucial roles of engine maintenance and performance. Consumer oriented policies may also more precisely targeted impact on sulfur emissions, regarding their distribution in time and space.

6.1 Manufacturing policies

Instruments aimed at manufacturing would concern either fuel or engines. These approaches will be discussed below. However, regulations can be more effective when they are combined; for instance, low-sulfur fuel makes possible the use of certain types of emission-reduction engine technology.

6.1.1 Fuel policies

For controlling the amount of sulfur in diesel fuel, a fairly blunt instrument would limit the amount of diesel fuel itself. One market-based approach to do this would be to reduce the subsidies and incentives to diesel fuel production. Among these are tax breaks for oil exploration and accelerated depreciation schedules.

A more precisely targeted instrument would focus on reducing the amount of sulfur per gallon of refined diesel fuel. Two approaches suggest themselves: a tax on sulfur (or sulfur concentrations), and a set of tradeable sulfur (or sulfur concentration) permits. The quantity of permits (or charge on emissions) could decrease (increase, respectively) over time to meet desired emission levels. Because of the interference of sulfur with engine emission control devices, there is a very steep section of the marginal benefit curve around the maximum non-interfering concentration of sulfur. This suggests that quantity-based approaches such as permits may be superior. On the other hand, the technology to reduce and measure sulfur concentrations works in finite steps rather than continuously, leading to inelasticities in the marginal cost curve. This would suggest that emissions charges are a superior approach. Thus it is as yet unclear which would be superior. The EPA, for its part, has allowed a certain amount of sulfur trading among refineries, in the context of its quantity limits on the concentration of sulfur.

6.1.2 Engine policies

For controlling the sulfur emissions of engines, there are again two approaches. A blunt approach is to increase fuel economy. Standards such as the CAFE standards can contain some market-based elements. For instance, standards may apply to a manufacturer's entire fleet, with averaging allowed. Second, a manufacturer may be able to trade emissions reductions with other manufacturers. Third, a manufacturer may be able to bank emissions reductions through time, making greater-than-needed reductions early on and saving the reductions to offset more difficult, heavier future reductions. [Rubin1993, Kling1994]All of these elements would promote low cost emissions reductions at the expense of high cost reductions, reducing the overall total cost. The US Congress considered such approaches for CAFE standards in the 1990 Clean Air Act amendments, but abandoned them [Kling1994]. The EPA adopted two limited trading programs for control of PM emissions from light-duty diesel vehicles and heavy-duty trucks, but these have yet to see extensive use[Kling1994].

A more precise instrument would target sulfur emissions themselves. Again, there are two approaches: differential charges for different levels of emissions, and permits allowing certain levels of emissions. Most of the literature has focused on tradeable emissions credits, as this is more compatible with the existing US emissions standards. For example, Lawrence White suggests that vehicle manufacturers could be issued transferable emission permits at the beginning of each model year (cited in [Kling1994]). McElroy, Hayes, and Olsen proposed requiring manufacturers to meet an average sales weighted emission level over their fleet of vehicles, with tradeable emission reduction credits (cited in [Kling1994]). California actually allows trading within emission classes, with fleet-wide standards and averaging within those classes ([Kling1994]), allowing banking and borrowing emissions through time ([Rubin1993]).

It should be noted that emission trading may not show large cost reductions compared to the current command-and-control policies. This is thought to be because consumer preferences and CAFE standards have led to lower-priced, smaller-cylinder vehicles with lower control costs[Kling1994]. However, banking emissions will smooth emissions over time – firms will choose to tighten controls now when standards are more lax, to prevent reductions in the future, when costs are expected to be higher because of tighter standards. This has the effect of lowering damages, assuming marginal damages due to pollution are increasing [Rubin1993].

6.2 Use policies

As with manufacturing policies, there are blunt and precise policies oriented towards users of diesel fuel. The blunt policies have the advantage of low transaction costs, but they are unlikely to be as efficient. It should be noted that particular incentives are likely to matter here: emissions-based policies don't seem to have much effect on miles driven, and distance-based policies don't have much effect on emissions[Harrington2001].

6.2.1 Polices to reduce fuel use

Blunt policies would target diesel fuel use, either directly or indirectly. Indirect policies would reduce driving, trucking, and farming themselves, and indirectly reduce diesel use. One market-based approach would be to reduce the subsidies to these activities. In the case of direct subsidies such as preferential taxation of farm diesel or price supports, the subsidy could be reduced directly. For indirect subsidies such as road construction, the users could be charged a fee, as with toll roads, or the ability to use roads could be limited with a system of vehicle or road permits.[Harrington2001]

Direct policies to reduce fuel use would generally take the form of a fuel tax. A system of permits to purchase fuel is also possible, but more unwieldy. There has been some concern that consumers' price elasticity of demand for fuel use is only moderate, and it has recently declined [Harrington2001]. This would make fuel taxes less effective than a permit system. However, the low elasticity appears to be one-sided. When fuel prices rise, motorists' fuel consumption declines, but when fuel prices decline, fuel consumption does not rise as much as expected. This may be because CAFE standards set a minimum fuel economy.[Harrington2001]

6.2.2 Policies to reduce sulfur emissions

More precisely targeted market-based policies to reduce sulfur emissions from diesel engines certainly exist. However, not all of them may meet with equal success.

The most efficient policy would be one that taxed sulfur emissions directly (or alternately, allocated transferable permits for emissions). However, because of the high number of vehicles, this has extremely high transaction costs. Various studies have proposed second-best policies that attempt to mimic the effects of emissions taxes with lower costs. Some examples are: inspection and maintenance programs combined with new-car controls and certain taxes (Eskelan and Devarajan); a gas tax that varies with pre-determined size and pollution characteristics of vehicles (Fullerton and West) ; and a emissions tax based on emission rates and miles driven (all examples cited in[Harrington2001]).

Inspection and maintenance programs deserve special attention. They directly address engine emissions that deteriorate over time ([Tietenberg2003]), and would seem to be an important component of any attempt to reduce emissions of vehicles in use. However, I&M programs based on mandatory standards have been very unsuccessful. In Arizona, for instance, 22% of vehicles taking the emissions inspections were never observed to pass it, and other vehicles are prohibitively expensive to repair [Ando2000]. Some economists have concluded that the costs of I&M programs exceed their benefits [Harrington1999].

This suggests two sorts of remedies. First, instead of command-and-control emissions standards, a market-based system of tradeable emissions permits or emissions charges would be more efficient. This is largely due to the fact that different vehicles have very different repair costs [Ando2000]. Since the costs of emission controls reduce sharply with modest decreases in emissions standards ([Ando2000]), permits may be more efficient than emissions charges. When consumers have information about effectiveness of repairing emissions controls, emissions charges are more effective than I&M plans, but they seem to be no more effective in the absence of this information[Harrington2001].

Second, it has been argued that many of the transaction costs of I&M programs are due to the fact that the liability for I&M is assigned to motorists [Harrington1999]. Alternative liability assignments may reduce transaction costs. Possible schemes include assigning the liability to manufacturers, auctioning off the liabilities for a group of vehicles, or increased use of vehicle leasing ([Harrington1999, Harrington2001]). It is probable that institutional users of diesel engines such as truckers and farmers may have lower additional transaction costs for these programs, since they are already subject to a certain amount of inspection and record keeping.

One successful market-based sulfur emission reduction policy that has been used in Europe is differential taxation for high-sulfur and low-sulfur fuel. This has led to adoption of low-sulfur fuel more quickly and more widely than expected [Harrington2001].

Another market-based policy that would reduce the use of vehicles that have high emissions is a car scrapping policy. This might, for example, allow a stationary emitter to offset its own emissions by buying and scrapping an older polluting vehicle. There is some disagreement about whether this is cost-effective ([Harrington2001]) or not ([Alberini1998]).

Some of the damages due to sulfur emissions are due to the density of emissions, so policies to address this are appropriate. Some market-based policies would include blunt policies such as congestion charges, and more precise policies such as issuing permits to drive cars with certain emission standards in certain regions [Tietenberg2003].

7 Sensitivity to Discount Rate

In general, when choosing a discount rate for valuing future benefits and costs, the social opportunity cost of capital is the appropriate rate to use. This rate varies with the riskiness of the project. However, choosing this rate is very subjective, and, depending on how much of the benefits and costs occur in the future, different choices of rates can lead to very different outcomes. It is prudent to use a number of discount rates, and to examine the sensitivity of the problem to the discount rate.

The health costs of sulfur emissions are generally recurring costs that occur in every time period with equal frequency, so they are sensitive but not very sensitive to the choice of discount rate. The same is true of the major non-health cost, visibility. Thus the benefits reducing sulfur emissions from diesel engines would be only moderately sensitive to the choice of discount rate.

On the other hand, there are many large costs of reducing sulfur emissions that occur up front. Refineries have to be upgraded and engines have to be redesigned. Because these occur immediately, they are insensitive to the choice of discount rate. Other costs, such as transaction costs of vehicle inspection programs, occur regularly and are moderately sensitive to the discount rate.

Thus, a high discount rate would make the net benefits of sulfur emission reduction look somewhat worse. This is since the present value of benefits would decrease more than the present value of costs, but only to the extent that the cost of developing new engines and refineries is large and done up-front.

8 Conclusion

There are several externalities that cause inefficiently high levels of sulfur emissions from diesel engines. Efficiency and fairness would suggest that these be removed or ameliorated. The estimated benefits are much higher than the projected costs of standards-based regulations to reduce them. However, it is possible that the costs of the EPA's regulations have been seriously underestimated, and that the health benefits have been overestimated. This has happened in the past: the net discounted value of the US regulation of automobile emissions has been low or even negative so far [Tietenberg2003]. It would therefore be prudent to examine the ways in which market-based policies can be used, not only to reduce costs, but to allocate costs to those that produce them. This would lead to a more efficient outcome.

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