THE ECONOMIC IMPACTS OF NO_x AND PARTICULATE MATTER EMISSIONS REGULATIONS ON THE HEAVY-DUTY DIESEL ENGINE INDUSTRY

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1.0 INTRODUCTION

This report presents estimates of the magnitude of the economic impacts that could result from potential heavy-duty diesel engine emissions regulations. The emphasis is on the effects on the five largest domestic producers of heavy duty diesel engines (HDDE's)--Caterpillar, Mack, International Harvester, Detroit Diesel-Allison, and Cummins--because these firms would be affected most directly. Costs to the general public are also examined.

Three of the four sections numbered 2 through 5, that compose the body of the report, are described briefly in this introductory section. Section 2 provides some background on the industry. Section 3 lists the provisions of the sets of regulations that are analyzed in the report, and describes the steps that manufacturers of engines would have to take in order to comply with the regulations. Section 4 presents the results of the analysis, while Section 5 describes the methodology used in the study. These are followed by a set of appendices that present data and detail on the derivation of some of the inputs to the analysis.

1.1 Proposed Regulations

The proposed regulations applicable to heavy duty trucks would limit the amount of soot or particulate matter (PM) that could be emitted by trucks in excess of 8,500 lbs gross vehicle weight (GVW), and would tighten current limits on emissions of oxides of nitrogen (NO_x). The proposed limits of 0.6 grams of PM per bhp-hour and 6.0 grams of NO_x per bhp-hour would take effect in the 1987 model year. For EPA's preferred alternative, the limits would be tightened for the 1990 model year to 0.25 g/bhp-hour for PM (except for the largest trucks, for which the limit would be 0.40 g/bhp-hour) and 4.0 g/bhp-hr for NO_x. The analysis compares these requirements to a baseline under which no changes in regulations would be made from the current, relatively lax standards. In addition, the report examines variants of the proposed regulatory package, under which the standards would be tightened in different ways after 1989.

1.2 Findings

The main findings of the study are as follows.

- Revenues from sales of HDDE's would be cut by a total of between $1.0 and $2.0 billion, depending on the stringency of the regulatory regime, over the years 1989 through 1992. This loss of revenue is three to six percent of the industry's baseline sales for that period. The loss is due largely to slower sales of trucks induced by the fuel consumption impacts of the regulations.

- Total resource costs to the economy would amount to between $3.5 and $7.5 billion over the same period, again depending on the stringency of the regime examined. The majority of this cost would be due to increased fuel usage by trucks, and would be borne by consumers of goods shipped by truck.

- The distribution of the impacts of the regulations among the HDDE manufacturers would be quite unequal. International Harvester might come close to breaking even, offsetting losses in truck sales with increased sales of its engines for use in the trucks of other manufacturers. Only Detroit Diesel-Allison, a division of General Motors, would be likely to be hurt severely. That division could lose more than twenty percent of its sales to its competitors.

- The shift from gasoline to diesel engines in smaller heavy duty trucks could be slowed or even halted by the proposed regulations. (This shift is virtually complete for the heaviest trucks.)

1.3 Methodology

The impacts of the regulations were assessed by estimating the hardware and fuel consumption effects of the standards, and then calculating the marketplace consequences of those changes.

The hardware and fuel consumption implications of the standards were determined largely on the basis of current emissions performance of the engine families produced by the domestic HDDE manufacturers and the work of Energy and Resource Consultants, Inc., a contractor for EPA, on the feasibility and effects of potential NO_x and PM regulations.

Market impacts of the hardware and fuel consumption changes induced by the regulations were estimated on the basis of empirically-derived measures of the price and performance sensitivity of engines and trucks. The market impacts methodology (and to a lesser extent the technological impacts methodology) is based on an earlier study of the effects of proposed regulations on the diesel truck industry written by Sobotka and Company, Inc.

2.0 BACKGROUND ON THE HEAVY DUTY VEHICLE INDUSTRY

This report may be understood more easily with some background knowledge of the heavy-duty engine and vehicle industry. This section addresses very briefly the vehicle and engine types, manufacturers, market relationships and current conditions for this industry.1/

2.1 Vehicles

This analysis focuses on the regulation of heavy duty diesel engines. Most of these engines are used in vehicles of more than 19,500 pounds of gross vehicle weight (GVW), and most of these vehicles are trucks used commercially for the transport of freight (as opposed to personal transportation, a common function of smaller trucks). Some buses are also in this vehicle weight category.

1/ Other sources provide more extensive background information in these areas. See, for example, "The Effects of Potential EPA Regulation on the Heavy-Duty Vehicle Industry, Part One: Description of the Industry" (Sobotka and Company, Inc. for the U.S. EPA) (1982).

Vehicles of greater than 19,500 pounds GVW are conventionally divided into three gross weight classes: those over 19,500 pounds but under 26,001 pounds fall into Class 6; those between 26,001 and 33,000 pounds are Class 7; and the heaviest trucks are Class 8. At the lighter end of this continuum, the typical vehicle is a single-unit truck (that is, the cargo compartment and cab are permanently connected) used for intracity delivery, which travels about 100 to 200 miles a day. The heaviest trucks consist of a tractor comprising the engine and the cab, and a separate trailer (or trailers) for the cargo. These combinations typically see very intensive intercity use.

2.2 Engines

Heavy-duty vehicles may be powered either by gasoline or diesel engines. Each type's characteristic advantages and disadvantages suit it to particular applications. The gasoline engine is light and inexpensive, suiting it to smaller, less intensively used vehicles. The diesel engine is much more expensive to purchase, but lasts considerably longer (up to 500,000 miles, with an overhaul at some point) and uses less fuel--as little as 50%-70% as much as a comparable gasoline engine. These advantages become more important the more heavily the vehicle is used, and the more costly fuel becomes. Diesels have been the overwhelming choice for the largest trucks and have been spreading among the lighter classes as fuel prices have risen.

2.3 Diesel Engine Manufacturers

The domestic producers of diesel engines for heavy-duty vehicles are--in order of engine sales revenues--Cummins, Detroit Diesel-Allison (a subsidiary of General Motors), Mack (substantially owned by Renault), Caterpillar, and International Harvester. The financial conditions of these firms vary widely; General Motors is financially robust, while International Harvester has been kept from bankruptcy by renegotiating its debts. The firms also differ in their relative degree of exposure in the market for engines. Caterpillar produces heavy equipment in addition to engines. IH's diesel engines are a small part of its business in comparison to its farm equipment and truck assembly operations, and it also builds gasoline engines for heavy-duty vehicles. Mack builds trucks in addition to engines. Detroit Diesel is part of General Motors, which is of course a tremendous presence in the automotive sector, participating in the markets for heavy-duty gasoline engines and trucks among others. Only Cummins derives virtually all of its revenues from the production of diesel engines.

2.4 Market Relationships

The heavy-duty vehicle industry has much in common with the light-duty vehicle industry. Many of the same firms participate in each industry, and the basic technologies embodied in products and used in production are similar. But production is organized very differently in the heavy-duty vehicle industry, where it is much more likely for firms to purchase major components from each other than in the light-duty industry.

Some of the producers of diesel engines build diesel engines only; other firms assemble trucks using their own components and components (including engines) purchased from other firms. Still other firms engage in vehicle assembly only, without manufacturing major components themselves. These market relationships give truck purchasers a great deal of flexibility in engine choice--a purchaser may generally specify within broad bounds whatever engine by whichever manufacturer he favors, regardless of the truck manufacturer with which he chooses to do business. (Historically, however, Mack engines have been available only in Mack trucks.)

This market structure also means that it is possible to study the impact of regulations that affect the engines largely by concentrating on the engine builders. Assemblers of trucks will be able to avoid much of the cost of complying with the regulations, as it is the engine manufacturers' responsibility to do the research and to make the changes needed to ensure compliance. If any particular engine is affected more seriously than the rest, truck manufacturers will generally be able to substitute a competing model, as specified by their customers.

2.5 Current Market Conditions

The heavy-duty vehicle industry is highly cyclical, and firms in the industry are vulnerable to general economic downturns. The replacement of an aging truck is an expensive proposition which can be postponed easily by an owner if profits seem uncertain, credit becomes tight, or volumes of goods needing shipment contract temporarily.

The industry is still recovering from a profound slump, which had cut sales virtually in half from their previous peak. In addition to this cyclical impact, the industry's growth prospects may have dampened permanently with the maturation of the industry, the completion of the interstate highway system, and rising operating costs. At the same time that these problems have surfaced, the firms in the industry have been spending heavily on the development of new products, including both smaller and more fuel efficient diesels.

3.0 PROPOSED REGULATORY REGIMES AND THEIR TECHNOLOGICAL CONSEQUENCES

This section describes the regimes considered in the study and the changes in engines expected to be made in order to comply with regulations.

3.1 Regulatory Regimes

Eight different regimes (or sets of standards) are compared in this report to a no-further-action regime. The regimes follow closely the regulatory options under consideration by EPA.

The regimes are identical for the years 1987, 1988, and 1989; standards for those years are set at 0.6 grams per brake horsepower per hour (abbreviated as grams or "g" henceforth) for PM, and 6.0 grams for NO_x. (The standards are set on the basis of emissions per unit of work produced because larger engines naturally emit more than small engines.) These standards are moderate in stringency; they would require on the order of twenty to forty percent reductions from current emissions levels for most engines.

One option would be to continue these levels for the standards beyond 1990. Other options would be to lower the NO_x standard to 4.0 grams, or to lower the PM standard to 0.4 or 0.25, or to combine these alternatives. The eight regimes considered assume standards set at the following levels:

Exhibit 3.1
EMISSIONS STANDARDS BY REGIME

REGIME	STANDARDS FOR 1990 AND BEYOND
1	(no change in current standards; baseline for comparison)
2	0.6 g for PM, 6.0 g for NO_x
2'	0.6 g for PM, 4.0 g for NO_x
3	0.4 g for PM, 6.0 g for NO_x
3'	0.4 g for PM, 4.0 g for NO_x
4a	0.25 g for PM, 6.0 g for NO_x
4a'	0.25 g for PM, 4.0 g for NO_x
4c	0.25 g for PM for medium-heavy trucks; 0.4 g for PM for large, line-haul trucks; 6.0 g for NO_x for all
4c'	0.25 g for PM for medium-heavy trucks; 0.4 g for PM for large, line-haul trucks; 4.0 g for NO_x for all

3.2 Engine Changes Likely to be Needed for Compliance

3.21 Steps to Control NO_x Emissions

Manufacturers have indicated that the following steps might have to be taken to comply with NO_x standards at levels in the range of those examined in this report:

- Changes in injection timing;
- Exhaust gas recirculation (EGR);
- Electronic control units (ECUs) (to control EGR systems, and/or to reduce fuel use impacts of timing retardation by allowing the timing to vary);
- Combustion chamber redesign;
- Changes in fuel injectors;
- Turbocharging;
- Charge air aftercooling or intercooling; and
- Improvements in aftercooling or intercooling.

Of these, exhaust gas recirculation (EGR) is likely to be avoided unless NO_x standards were particularly strict, because of its tendency to raise PM emissions and fears that it may damage the engine. Electronic control units (ECU's) and trap-oxidizers (traps) are not likely to be generally available until the 1990's. In the near term, primary control techniques will probably be improvements in input air cooling for turbocharged engines, and retardation of timing.

For this study, it has been assumed that all turbocharged engines will be fitted with advanced charge coolers in the near term, for reasons apart from the regulations, but not with EGR or ECUs. It is assumed that ECUs will be added to all engines in the intermediate term, again independent of the regulations. EGR, it is assumed, will be applied to all engines if NO_x regulations are sufficiently stringent. A few other specific assumptions are made, on the basis of conversations with the manufacturers. The most significant of these is that Caterpillar's naturally aspirated 3208 model will disappear, leaving only a turbocharged version of the same basic engine. This change is treated in the study as though a turbocharger were added to the naturally aspirated 3208, increasing its power and cost but helping to lower its emissions. The changes for the individual engine families in the near and intermediate terms are summarized in Exhibit H.2.

3.22 Use of Trap-Oxidizers for PM Control

Some engines are inherently low enough in PM emissions to meet the less stringent PM standards without any add-on emissions reduction hardware--that is, their "engine-out" particulate levels may already be below some of the proposed standards. Others will need careful matching of turbochargers to engines, and modifications in their fuel injection systems and combustion chambers to reduce their engine-out PM levels.

For each engine there exists some set of standards that cannot be met by reducing engine-out levels alone. To meet that set of standards, an add-on device would have to be used to reduce emissions still further. Trap-oxidizers show potential for being able to remove fifty to sixty percent--and perhaps up to ninety percent--of the engine-out PM. These devices are muffler-like filters for the exhaust stream, designed to catch the soot-like PM and burn it away. It is not expected, however, that these devices will be ready for application to heavy duty trucks until the 1990's.

The tighter PM and NO_x standards proposed for the post-1989 period are likely to require some or all engines to employ trap oxidizers. The NO_x standard is important because of the tendency of PM emissions to increase as NO_x emissions are forced down.

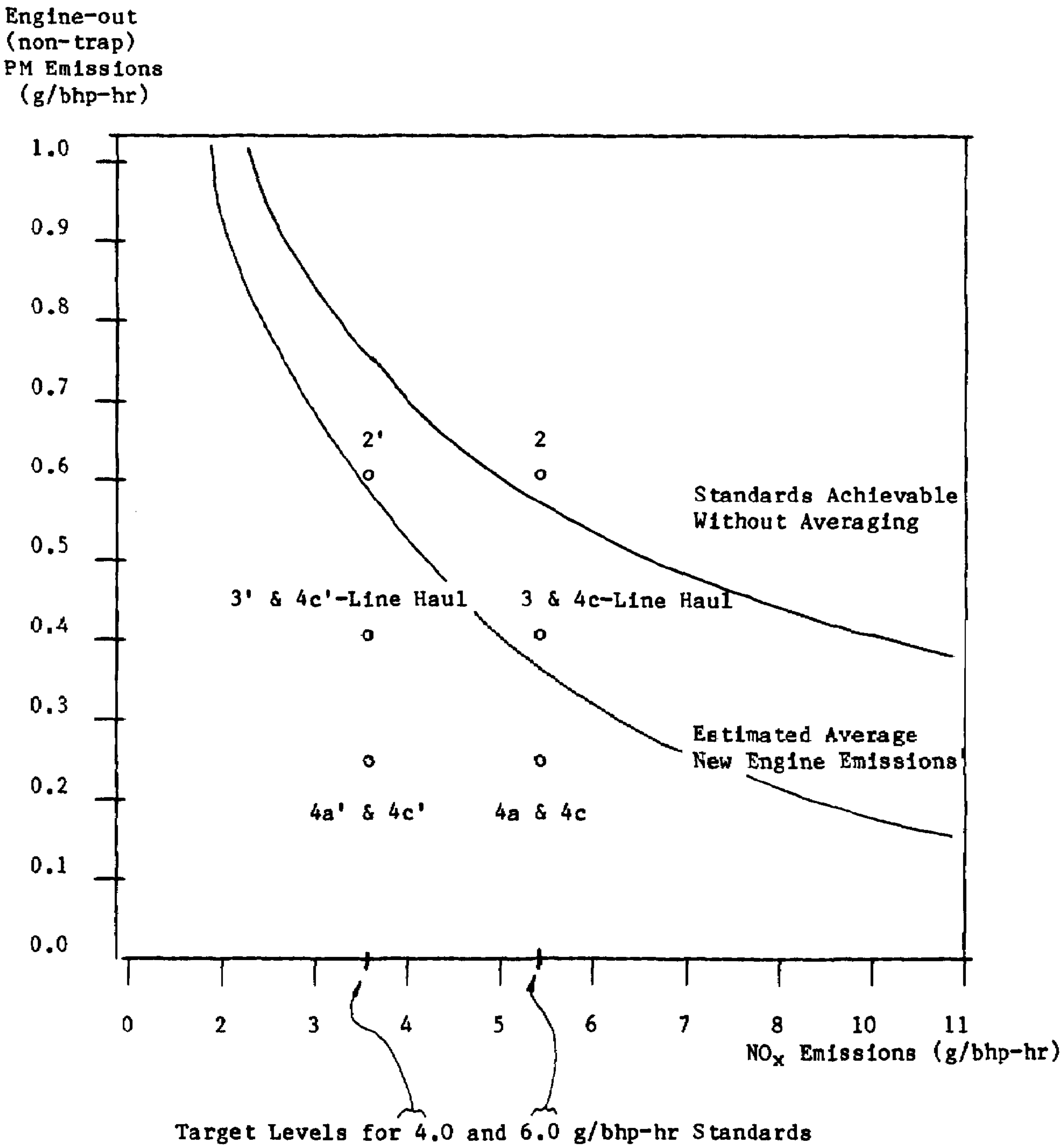
Predictions as to the need for some or all engines to have traps fitted to them under the various regimes were made on the basis of estimates made by Christopher Weaver of ERC, Inc. of the average PM and NO_x levels achievable without traps by HDDEs in the time frame 1990-1991. Exhibit 3.2 shows ERC's estimates of the achievable PM emissions without traps in the intermediate term at different NO_x levels, compared to the levels mandated by the regimes.

ERC's analysis indicates that only the least stringent regime would be achievable without the use of traps by many engine families, if each engine of each engine family were required to meet the standards. The averaging of emissions across families within firms would allow firms to comply with considerably tighter standards.

It was assumed for this report that intra-firm averaging of PM emission would be allowed in each regime. If averaging were not permitted, trap usage would be much more widespread under some regimes, and some engines might be impossible to bring into compliance even assuming that fairly efficient traps were available.

For some regimes, no traps would be needed to assure that the standards were met on average. Under other regimes, all engines might have to be fitted with traps. For a number of other regimes, however, the situation is not clear-cut. The average engine's PM emissions might have to be reduced by only

Exhibit 3.2
REGIMES COMPARED TO ESTIMATED ACHIEVABLE ENGINE-OUT EMISSIONS



Estimated Achievable Intermediate-Term Engine-Out Emissions Standards and Fleet-Average New-Engine Emissions Levels, Compared to Regimes (Relationship of PM to NO_x Taken from ERC Report by Weaver et al.)

about 30%--a reduction that could easily be surpassed by a moderately efficient trap. This means that, in these in-between cases, some fraction of trucks could be left without traps. The actual fraction of engines that would need traps in cases like this is uncertain, and depends on potential engine-out particulate levels and on the efficiency of traps not yet in service. Because no reliable information was available on these factors, a figure of 50% was selected for the percentage engines of that would need traps in the in-between cases--and it was assumed that this percentage would be the same for all engine families. (Some engines have considerably higher smoke emissions, and smoke emissions bear some relation to measured PM emissions. It was beyond the scope of this study, however, to attempt to draw implications from smoke levels to the need for traps.)

4.0 RESULTS

The impacts of the proposed regulations may be examined in a number of ways. The regulations, by increasing the costs of purchasing and operating heavy duty diesel trucks, would reduce (or at the very least postpone) the sales of trucks; this would reduce the revenues of engine builders and truck assemblers. To the extent that costs of compliance could not be passed on to engine and truck purchasers, the costs of the engine manufacturers would be increased. (This is expected to occur to a negligible extent). Increases in first costs, reductions in power, and increases in fuel consumption would reduce the value of the engines --thereby increasing transportation costs, and reducing the net value of the economy's output. Increases in the costs of buying and operating diesel engines could also result in slower adoption of diesels in the size class in which diesel and gasoline engines are expected to compete most intensely--Class 6. These impacts are considered in turn in this chapter.

4.1 Revenue Impacts by Year

Exhibit 4.1 presents the industry-level engine revenue reductions, compared to the projected baseline, that would be incurred by all five large domestic HDDE

Exhibit 3.3 summarizes the trap-use percentages assumed for the regimes.

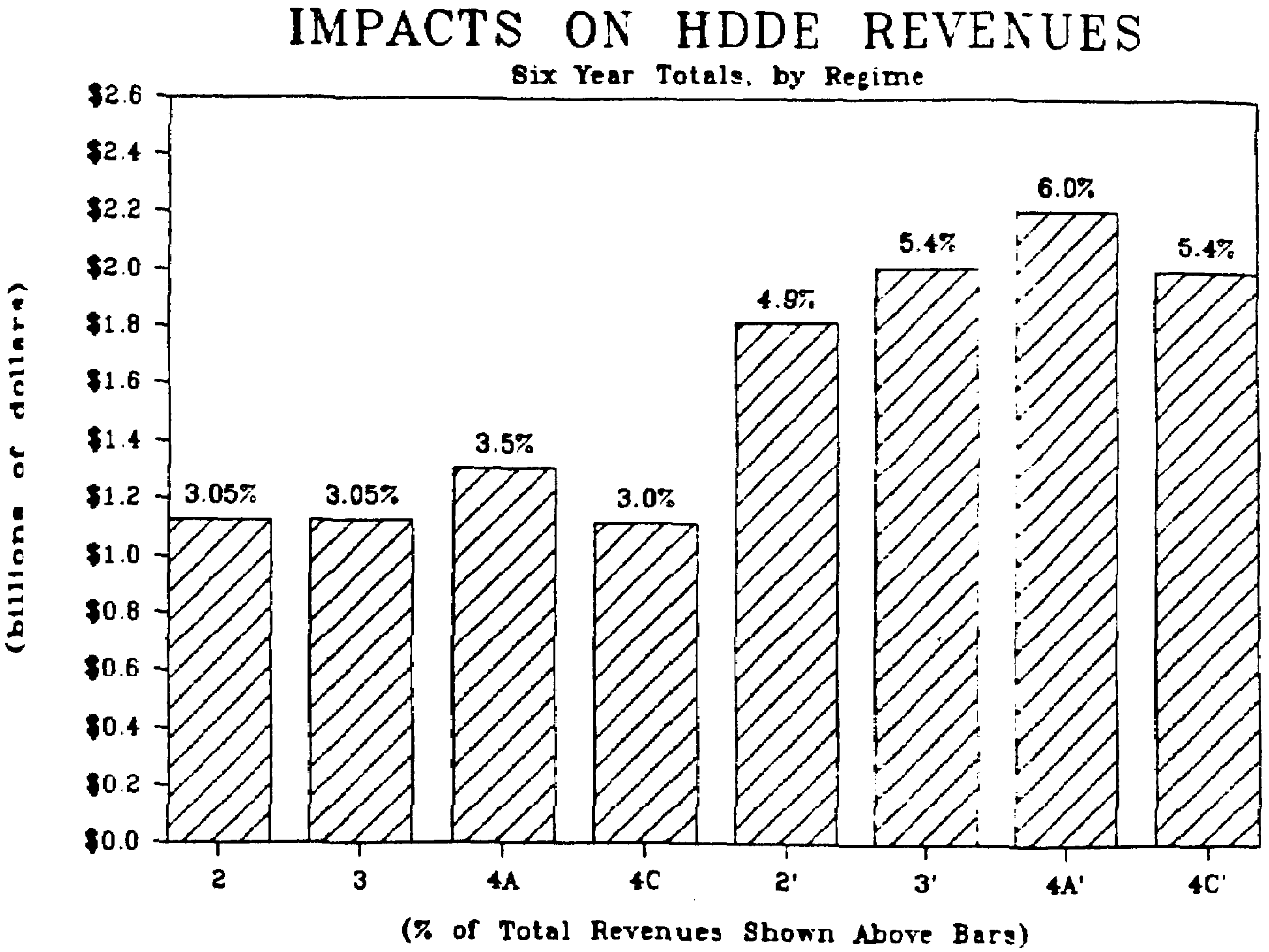
Exhibit 3.3
ASSUMED TRAP USAGE UNDER DIFFERENT REGULATORY REGIMES
(Intermediate term)

	REGIME							
	2	2'	3	3'	4a	4a'	4c	4c'
				(g/bhp-hr)				
NOx STANDARD	6.0	4.0	6.0	4.0	6.0	4.0	6.0	4.0
NOx TARGET	5.4	3.5	5.4	3.5	5.4	3.5	5.4	3.5
NON-LINE HAUL PARTICULATE STANDARD	0.6	0.6	0.4	0.4	0.25	0.25	0.25	0.25
PERCENTAGE OF NON-LINE HAUL TRUCKS NEEDING TRAP OXIDIZERS	0%	0%	0%	50%	50%	100%	50%	100%
LINE HAUL PARTICULATE STANDARD	0.6	0.6	0.4	0.4	0.25	0.25	0.40	0.40
PERCENTAGE OF LINE HAUL TRUCKS NEEDING TRAP OXIDIZERS	0%	0%	0%	50%	50%	100%	0%	50%

Note: All regimes assume averaging of PM emissions. Even so, Regime 4a' is of borderline achievability, as it would require good engine-out performance and traps providing high removal efficiencies.

All regimes assume standards of 6.0 and 0.6 grams/bhp-hr for the period 1987 through 1989, with no need for trap-oxidizers.

Exhibit 4.1



TOTAL REVENUE LOSSES BY HDDE PRODUCERS
(Millions)

SHORT TERM	1987	1988	1989	TOTAL	SUM OF SHORT AND INTERMEDIATE TERM
All Regimes	$188	$220	$248	$657	
INTERMEDIATE TERM	1990	1991	1992	TOTAL	
2	$156	$156	$159	$470	$1,127
2'	$360	$387	$413	$1,159	$1,816
3	$156	$156	$159	$470	$1,127
3'	$415	$452	$488	$1,355	$2,012
4a	$208	$216	$225	$650	$1,307
4a'	$471	$518	$563	$1,552	$2,209
4c	$152	$153	$155	$460	$1,117
4c'	$419	$448	$477	$1,344	$2,001

firms in each of the six years covered by the study.[1] Because the regimes do not differ for the short term, the figures are not broken down by regime for the years 1987, 1988, and 1989. The total for this period is about two-thirds of a billion dollars, or about four-and-one-half percent of the total projected engine revenues. In absolute numbers, about 16,000 fewer engines and trucks would be sold each year compared to levels that are otherwise projected to occur.

In the intermediate term, the costs range from about a sixth to a half billion dollars per year, for a total of half to one-and-a-half billion dollars over three years. The high end of this rate of loss (again, compared with baseline EPA projections) approaches ten percent of engine revenues, equivalent to about 40,000 fewer trucks and engines per year. In terms of employment, according to a very rough calculation (assuming $150,000 in value of shipments per production worker) a revenue reduction of a half billion per year would be associated with a loss of about 3,300 jobs.

Lowering NO_x standards from 6.0 to 4.0 grams increases revenue losses more significantly than lowering PM standards. This is because tighter NO_x standards in and of themselves increase fuel consumption more rapidly than do tighter PM standards, and also because a tighter NO_x standard tightens the effective PM standard--thereby increasing the need for traps.

4.2 Revenue Impacts by Firm

It is somewhat hazardous to try to project which firms would be hurt most by the regulations, because (among other reasons) the most stringent standards would not even take effect for several years, and there will be changes in markets

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[1]/ The revenue reductions listed for the engine manufacturers overstate to some degree the dollar magnitude of the reductions borne by the manufacturers. Because the revenue reductions are based on changes in unit sales multiplied by approximate retail prices, they include the revenue reductions that would be suffered by vehicle assemblers and dealers. The reported percentage reductions in revenues are not affected by this factor.

and technologies taking place in the interim. However, based on current emissions levels and technologies, it seems likely that one company, Detroit Diesel-Allison, would be affected to a significantly greater extent than the others. Exhibit 4.2 shows the total engine revenue losses over the six years broken down by firm for each of the regimes. In fact, DD-A's engine revenue losses are between fifty and one-hundred percent of the total, with IH and Cummins gaining in some cases. In comparison to DD-A's projected revenues, its losses are in the range of a fifth to a quarter of the total. In absolute numbers, DD-A's losses might average between 12,000 and 16,000 fewer sales of engines per year.

International Harvester would be likely to gain engine revenues of a few percent, due to the fact that its engines are relatively new and clean. As described below, however, these gains in engine revenues would be likely to be offset--or more than offset--by losses in truck revenues. Cummins might gain in some cases, but only marginally, and under other regimes it would lose revenues.

4.3 Truck Assembly Revenue Reductions

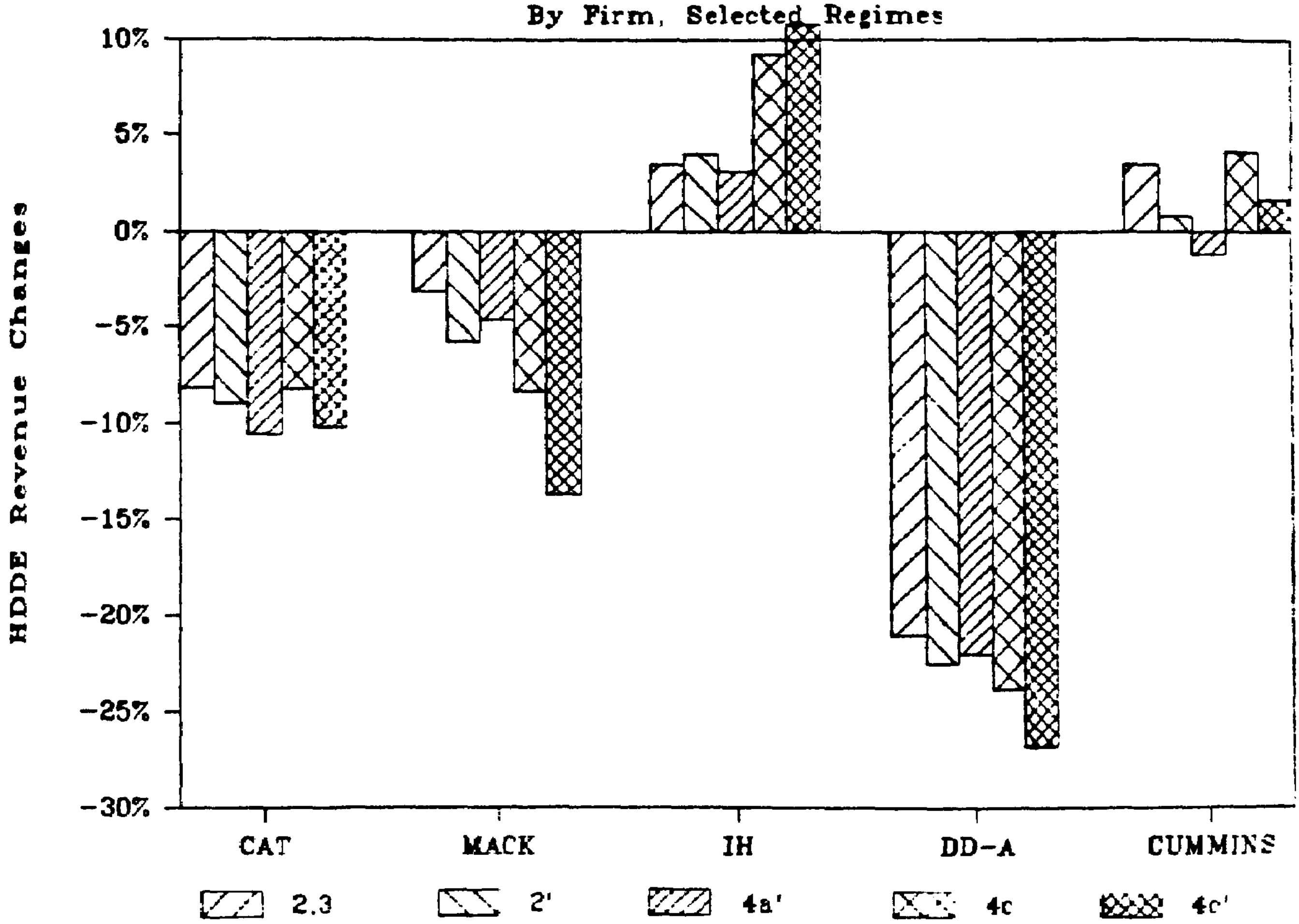
Three of the HDDE manufacturers are also important assemblers of completed trucks. These firms, International, Mack, and GM (the parent company of DD-A) would lose revenues due to reduced truck sales as well as because of reduced engine sales. Exhibit 4.3 shows the six-year total revenue reductions for the three firms. To avoid double-counting of losses from engine sales, the figures in the table are for truck revenues net of engine values.

Translation of the revenue losses into reductions in profits is not easily done with precision. When unit sales fall, revenue reductions are partly offset by reductions in the total costs of production, as the use of labor, materials, and other inputs is reduced. An analysis of the relationship of Cummins' profits to its capacity utilization showed that prices are roughly twenty percent above marginal costs. Of each dollar and twenty cents of revenues lost, therefore, that company could reduce its costs by about one dollar and

Exhibit 4.2

IMPACTS ON HDDE SALES

By Firm, Selected Regimes



CHANGES IN ENGINE MANUFACTURER REVENUES UNDER DIFFERENT REGULATORY REGIMES
(Millions and Percent of Total)

REGIME:	2	2'	3	3'	4a	4a'	4c	4c'
CAT	($518) -8.2%	($572) -9.0%	($518) -8.2%	($620) -9.8%	($516) -8.1%	($670) -10.6%	($522) -8.2%	($646) -10.2%
MACK	($129) -3.1%	($236) -5.8%	($129) -3.1%	($214) -5.2%	($107) -2.6%	($191) -4.7%	($342) -8.3%	($565) -13.8%
IH	$129 3.4%	$150 4.0%	$129 3.4%	$133 3.6%	$77 2.1%	$115 3.1%	$345 9.2%	$395 10.5%
DDA	($1,200) -21.1%	($1,283) -22.5%	($1,200) -21.1%	($1,270) -22.3%	($1,190) -20.9%	($1,255) -22.1%	($1,357) -23.8%	($1,525) -26.8%
CUMMINS	$591 3.5%	$125 0.7%	$591 3.5%	($41) -0.2%	$430 2.5%	($207) -1.2%	$706 4.1%	$287 1.7%
TOTALS	($1,127) -3.0%	($1,816) -4.9%	($1,127) -3.0%	($2,012) -5.4%	($1,307) -3.5%	($2,208) -6.0%	($1,170) -3.2%	($2,054) -5.6%

Exhibit 4.3
TRUCK SALES LOSSES BY COMPANY
(Millions)

REGIME	FIRM: MACK	IH	GM
2	$150	$270	$162
2'	$258	$474	$294
3	$258	$474	$294
3'	$294	$540	$330
4a	$186	$336	$188
4a'	$324	$606	$372
4c	$132	$246	$156
4c'	$270	$522	$330

would suffer a reduction in profits of about twenty cents. Because this split between profits and costs might not hold at different times and for different firms, the reductions in net revenues shown in Exhibit 4.4 are given only approximately, for a range of markups over marginal costs from ten to thirty cents over marginal costs.

Manufacturers might also lose net revenues if they are forced to take steps to reduce emissions that increase production costs more for their products than for competing products (including, most likely, potential competitors as well as existing competitors). These costs probably could not be recovered in higher prices without counter-productive reductions in sales volume. The need to add traps to an unusually large number of engines would be an important instance of this; other possible instances would be less significant. Unfortunately, it was not feasible to identify with any accruacy which engine families would be particularly likely to need traps within the scope of this project.

4.4 Losses to Economy

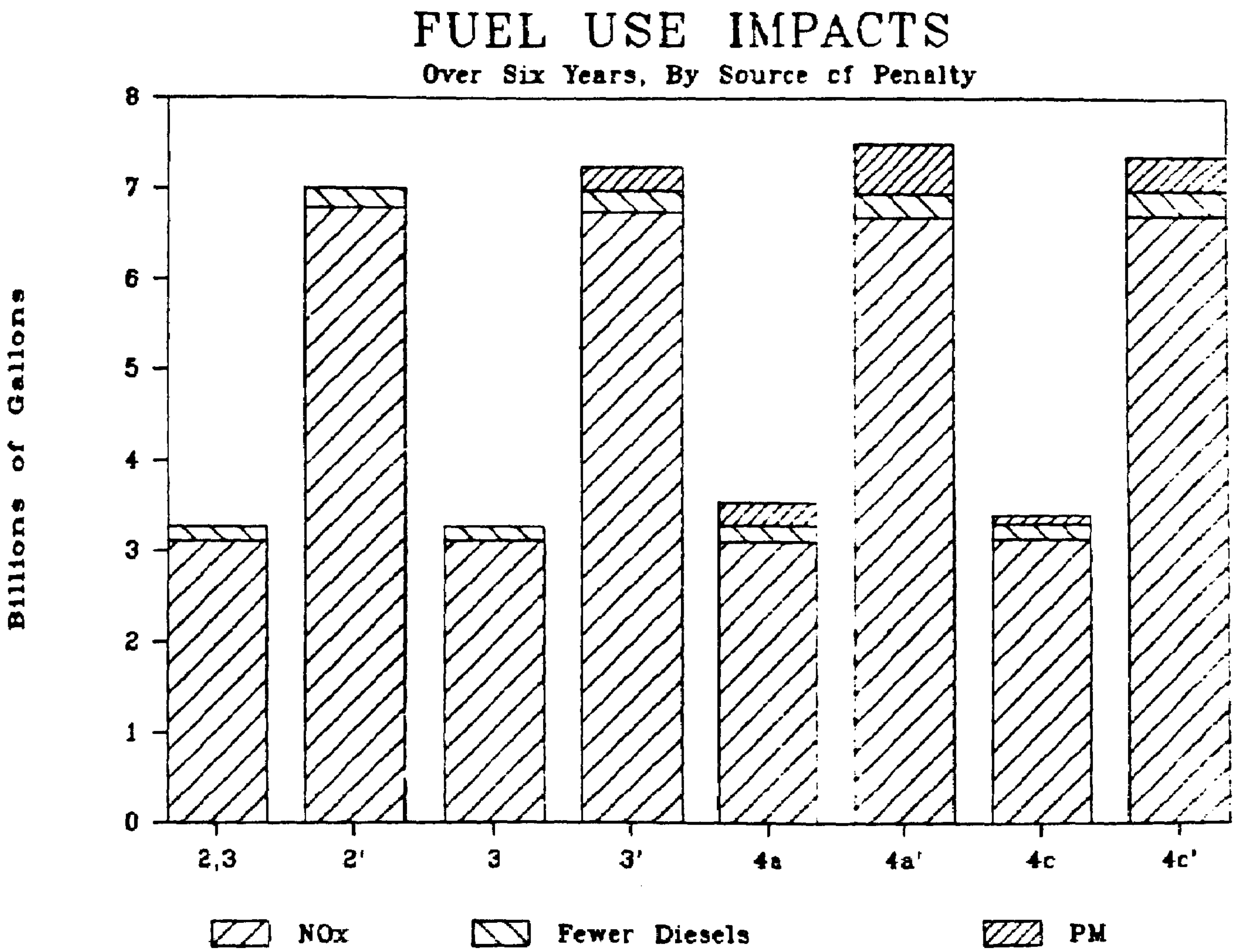
The revenue losses to the HDDE manufacturers would be among the most dramatic impacts of the regulations, partly because they would be concentrated on one relatively small sector of the economy. The economy as a whole would also be affected. While the impact on the national economy would be smaller in percentage terms than the impact on the HDDE industry, the total dollar impact would be much greater. Increases in fuel consumption resulting from the effects of the NO_x standards would be by far the most important source of the costs imposed on the economy. Fuel consumption losses due to traps, and due to the substitution of less efficient gasoline engines for diesels in some small trucks would also contribute to increased use of fuel. The total number of additional gallons of fuel used by trucks sold in the years 1987 through 1990 as a consequence of the regulations are shown in Exhibit 4.5. The exhibit also shows the breakdown of the total by the source of the consumption penalty. The magnitude of increased fuel usage, from just over three to over seven billion gallons in six years, may be compared to total imports of fuel: 3.33 millions barrels of

Exhibit 4.4
ESTIMATE OF CHANGES IN NET REVENUES
(estimated to be between 10% and 30% of changes in gross revenues)

(in millions of dollars, over six years; losses shown in parentheses; first and second line for each firm equal ten and thirty percent of changes in revenues, respectively)

FIRMS / REGIMES:	2	2'	3	3'	4a	4a'	4c	4c'
CAT	(67)	(83)	(67)	(91)	(70)	(100)	(65)	(92)
	(210)	(249)	(210)	(274)	(210)	(299)	(196)	(275)
MACK	(40)	(71)	(40)	(76)	(44)	(80)	(59)	(109)
	(120)	(214)	(120)	(227)	(133)	(239)	(177)	(326)
IH	(3)	(14)	(3)	(20)	(12)	(26)	19	7
	(10)	(42)	(10)	(59)	(37)	(77)	56	20
DD-A/GM	(120)	(128)	(120)	(127)	(119)	(126)	(136)	(152)
	(360)	(385)	(360)	(381)	(357)	(377)	(407)	(457)
CUMMINS	59	13	59	(4)	43	(21)	71	29
	177	38	177	(12)	129	(62)	212	86

Exhibit 4.5



FUEL USE IMPACTS

(In Billions of Gallons, Over 6 Years)

REGIME:	2	2'	3	3'	4a	4a'	4c	4c'
SOURCE OF IMPACT								
NO_x REGULATION	3.11	6.79	3.11	6.74	3.10	6.68	3.13	6.71
SLOWER DIESELIZATION	0.15	0.21	0.15	0.24	0.17	0.27	0.17	0.27
TRAPS	0	0	0	0.27	0.25	0.54	0.10	0.38
TOTALS	3.26	7.00	3.26	7.25	3.52	7.49	3.40	7.36

crude per day in 1983 [1], which is 1.22 billion barrels per year, or about 51 billion gallons for that year. Six year's imports at that rate would amount to about 300 billion gallons, so the regulations could add between one and two-and-a-half percent to domestic demand for imported oil.

The sum of monetized fuel consumption increases, first cost increases, and monetized performance penalties are shown in Exhibit 4.6. (Fuel cost increases have been discounted at 15 percent annually to allow for the fact that costs incurred in the future are less of a burden to society than are costs incurred in the present.) This sum, combined with the net revenue losses to firms, represent the real resource cost of the regulations. These cost increases are less than a tenth of a percent of GNP, and so would have an insignificant effect on the price level even if passed through into consumer prices.

4.5 Impact on Dieselization

The increased costs of using diesel engines is predicted to slow down the long-term trend away from using gasoline engines in trucks. With or without the regulations, larger trucks (Classes 7 and 8) are projected to be powered almost exclusively by diesel engines by the end of the period examined. The advantages of diesels for Class 6 trucks, which are smaller and less intensively used, are not as clear-cut. The projected shift toward the use of diesels in this class is projected to be slowed down moderately or even severely by reductions in the diesel's fuel economy edge. The projections are shown for different regimes in Exhibit 4.7.

5.0 OUTLINE OF METHODOLOGY

This section describes the steps taken in calculating the impacts of the regulatory regimes, and provides an example of the implementation of this methodology for one engine family. More detail on the derivation of some of the inputs to the calculations are provided in appendices.

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[1] Monthly Energy Review, May 1984, p. 40.

Exhibit 4.6
CHANGE IN VALUE OF PRODUCTS
(Millions)

SHORT TERM

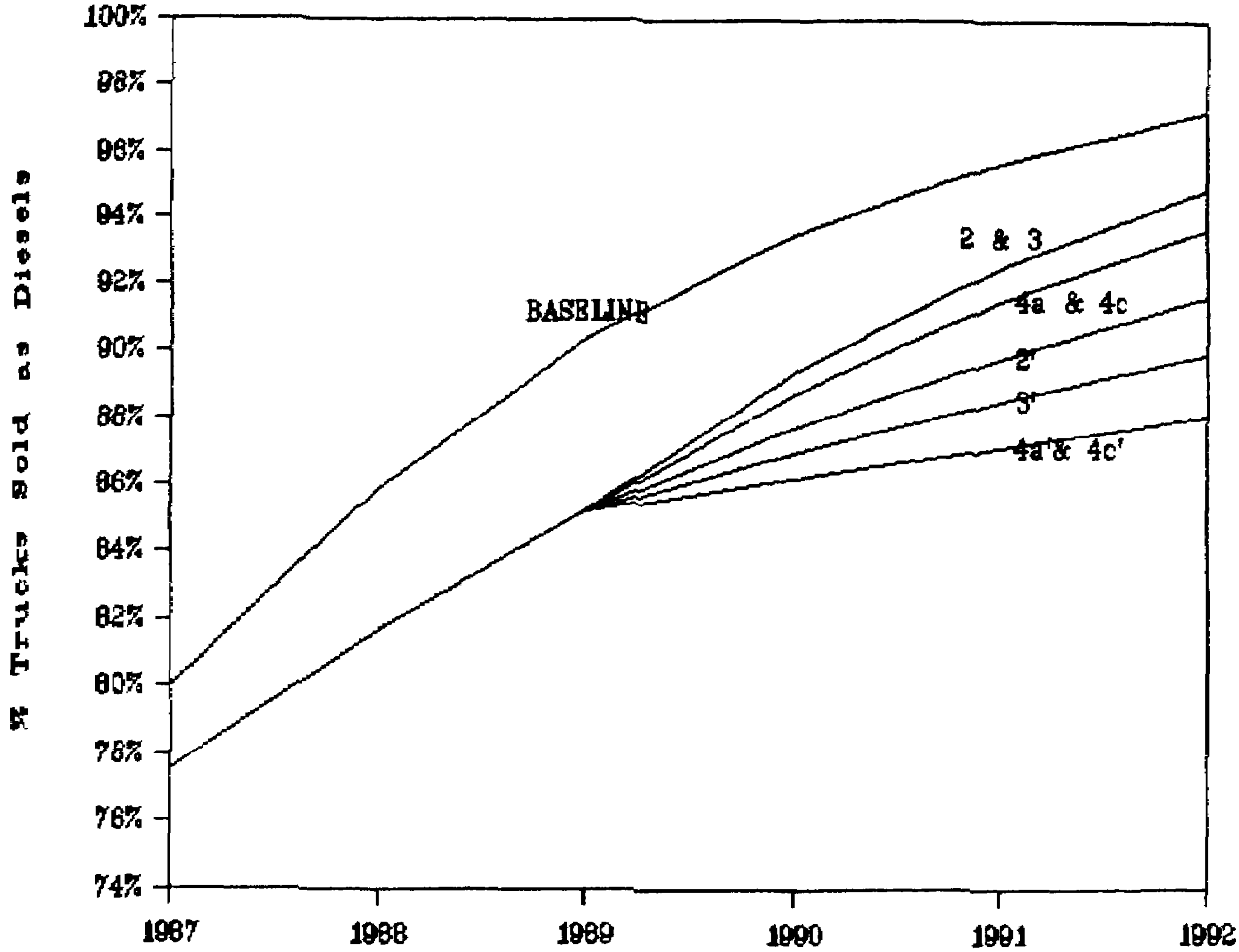
	1987	1988	1989	TOTAL
All Regimes	$790	$815	$848	$2,453

INTERMEDIATE TERM

	1990	1991	1992	TOTAL
2	$322	$336	$354	$1,011
2'	$1,240	$1,295	$1,367	$3,901
3	$322	$336	$354	$1,011
3'	$1,533	$1,601	$1,690	$4,823
4a	$608	$635	$670	$1,913
4a'	$1,825	$1,906	$2,012	$5,744
4c	$447	$469	$496	$1,412
4c'	$1,657	$1,737	$1,838	$5,232

Exhibit 4.7

IMPACTS ON CLASS 6 DIESELIZATION



CLASS 6 DIESELIZATION PERCENTAGES

	2	2'	3	3'	4a	4a'	4c	4c'
1987	77.6	77.6	77.6	77.6	77.6	77.6	77.6	77.6
1988	81.7	81.7	81.7	81.7	81.7	81.7	81.7	81.7
1989	85.2	85.2	85.2	85.2	85.2	85.2	85.2	85.2
1990	89.4	87.7	89.4	87.0	88.7	86.2	88.7	86.2
1991	92.6	89.8	92.6	88.6	91.5	87.2	91.5	87.2
1992	94.9	91.6	94.9	90.0	93.7	88.1	93.7	88.1

CHANGES FROM BASELINE

1987	-2.48	-2.48	-2.48	-2.48	-2.48	-2.48	-2.48	-2.48
1988	-4.20	-4.20	-4.20	-4.20	-4.20	-4.20	-4.20	-4.20
1989	-5.12	-5.12	-5.12	-5.12	-5.12	-5.12	-5.12	-5.12
1990	-4.09	-5.80	-4.09	-6.53	-4.76	-7.26	-4.76	-7.26
1991	-3.14	-5.88	-3.14	-7.17	-4.18	-8.52	-4.18	-8.52
1992	-2.34	-5.58	-2.34	-7.26	-3.50	-9.13	-3.50	-9.13

One of the basic aims of the analysis was to relate particular regulatory regimes (sets of numerical standards for NO_x and PM) to changes in revenues for each HDDE manufacturer. (Other quantities of interest, such as changes in fuel consumption and truck revenues were derived at various points in the process of calculated engine revenue changes.) The chain of analytical steps leading from the regimes to revenue changes may be broken down into two main parts: the technological impacts of the regulations on the engines and their performance, and the market impacts of these changes in the engines.

5.1 Technological Impacts of the Regulations

The analysis of the technological implications of the regulations may also be divided into two parts: deciding what changes would be likely to be made in the engines in order to meet the standards, and then calculating the likely effects of these changes on the engines' performance characteristics--their power and fuel economy.

5.11 Changes Likely to be Made in Engines

A range of sources was used to construct a balanced picture of the probable changes that would be made by the engine manufacturers in order to meet the different regulatory regimes. The main reference was work done by ERC on the feasibility and costs of NO_x and PM regulations, supplemented by assessments of EPA, the National Research Council of the AAAS, and informal discussions with the manufacturers concerning changes specific to individual product lines needed to meet particularly stringent regulations.

The various sources used were broadly consistent: traps and ECUs were considered very important elements in strategies to meet tight standards, but were not expected to be available in the near term; EGR would be avoided unless absolutely necessary; turbocharging, charge-air cooling, and improvements in charge air cooling would all be used where possible to lower emissions without losing too much in the way of efficiency. The marginal NO_x reduction technique, injection timing retardation, would be used sparingly because of its negative impacts on fuel efficiency. The precise assumptions made on the steps taken for each engine family are reported in Exhibit H.2.

5.12 Fuel Consumption and Performance Impacts of the Changes

Estimates of the impacts of the engine changes on fuel efficiency are among the most crucial steps in the analysis, because of the large increases in costs that stem from even relatively small percentage changes in fuel consumption. The method used to project changes in consumption, engine family by engine family, started with a general relationship between NO_x emissions targets based on research by NRC and quantified by Sobotka and Co. for an earlier study of the effects of the regulation of HDDEs. This relationship was then shifted in the direction of higher or lower fuel consumption penalties according to the baseline NO_x emissions level of the engine family considered, and the hardware changes assumed to be made in it. The overall results of the procedure, in terms of the average industry-wide fuel consumption increase projected for various regimes and time frames are close to those estimated by ERC and other observers. The projected increases in fuel consumption are higher than those estimated by EPA largely because EPA uses current fuel consumption levels as its baseline, rather than using consumption levels in the future in the absence of controls as a baseline. The difference arises from the fact that progress is expected in fuel efficiency both with and without further regulations. Because of this, fuel efficiency might not drop much from one point in time to another as regulations are phased in. The impacts of the regulations should be measured as the drop from what consumption could have been at the later time to what it would be including the regulations, and the indications are that the impacts measured in this way are likely to be significant.

The addition of traps would be likely to add a small increment to fuel consumption--on the order of 0.75% to 1.5% or 2.0%--due to slight increases in back pressure on the engines and the probability that extra fuel will be needed to regenerate the traps periodically. The most promising designs for traps should be able to keep this penalty to a minimum, and it has been assumed for this report that the most promising designs will be used.

The addition of traps is also expected to cut power output slightly--by about the same amount as the reduction in efficiency. While it has been said that this reduction probably would not be noticeable, it has been assumed for this report that the loss of horsepower caused by the traps would be valued by potential users of the engines at the same rate (in dollars per HP lost) as the market values horsepower generally. More powerful engines sell at proportionately higher prices, indicating that a one percent loss of power should be valued as, roughly, a one percent drop in the market value of the engine: buyers are assumed to act as though a $15,000 engine that loses 1% of its power output has had its price raised by 1%, or $150 dollars.

The three types of penalties--NO_x standard-induced fuel consumption increase, trap-induced fuel consumption increase, and trap-induced performance penalty, are combined into a single value by translating the fuel consumption increases into dollar amounts. This is done by multiplying the percentage changes in fuel consumption by an estimate of the total number of gallons used by typical trucks in different size classes, multiplying by an estimate of the price of diesel fuel per gallon, and discounting the added fuel costs back to the time of purchase of the truck to account for the fact that future cost increases are valued less highly than those in the present.

5.2 Market Impacts of the Reductions in the Value of the Engines

Sales of a particular engine family are assumed to be affected in three ways by changes in their value (whether due to increased fuel consumption, reduced power, or increases in costs of equipment like EGR or traps that would not otherwise have been added). First, an engine family that is affected more seriously than competing engines (those similar in horsepower and/or price range) is assumed to lose sales to other families even if the total number of engines sold stays the same. The degree to which sales are lost by one engine family is calculated using an estimate for the family-by-family price elasticity of demand for engines, the magnitude of the cost implications of the regulation relative to those facing competing engines, and the estimated price of the engine.

Second, even an engine that is burdened no more heavily than the average engine is assumed to lose some portion of its sales because the increases in the costs of buying and operating trucks will depress the sales of trucks. Slower truck sales will mean slower engine sales, with the degree of reduction calculated using the average prices of trucks of different classes, the average increase in the costs of buying and operating the trucks due to the regulations' impact on the engines, and a measure of the demand elasticity for trucks.

Finally, even if the same number of trucks were sold, the number of diesel engines could fall if more buyers chose competing gasoline engines instead of more seriously affected diesels. This impact was estimated by comparing the rate of dieselization (shift from gasoline to diesel engines) with and without the regulations. The model used to project changes in the use of diesels is a straightforward logistic diffusion model (one that assumes that the spread of a new, superior technique starts slowly, accelerates, and then tapers off as saturation is reached) using the relative advantage of diesel engines as a parameter determining the speed of the process. The model was calibrated using data on the effects of fuel price increases--which increase the attractiveness of the highly fuel-efficient diesel--on diesel usage rates.

Once the percentage changes in sales shares of each of the thirty-two engine families in the study were calculated, they were multiplied by the estimated retail price of the engines to yield changes in revenues for the engine manufacturers, truck assemblers and dealers combined.

5.3 Illustration of Calculations

To illustrate the mechanics of the model used to calculate the effects of the regulations, a typical engine family will be followed through the analysis. The engine family used as an example is the Detroit Diesel-Allison V8-8.2, and the year 1992 for Regime 4a' was chosen for the calculations.

The model makes use of a number of facts, taken from various sources or calculated, about the engine family, the market, and the requirements of the regulatory regime. The V8-8.2 is a low-priced (about $8,000 retail equivalent), low-powered engine, and has therefore been assumed to compete only with other engine families used in Class 6 trucks. Changes assumed to be made in the engine are based on the emissions standards of the regulatory regime. Regime 4a' requires NO_x levels to be below 4.0 grams; this means that manufacturers would have to aim at a target about a half of a gram lower to provide a safety margin. PM levels would have to average 0.25, which would require traps on virtually all engines (especially given the low NO_x targets of this regime). Thus, a trap is assumed to be added to the V8-8.2. EGR would probably be used to some extent to meet the NO_x target, and an ECU would, by 1992, be used on this engine. This engine is not turbocharged, and so no cooling of the intake air would be required.

In order to determine the impacts on truck sales, a truck demand elasticity estimated to be -0.46, and an engine family demand elasticity of -5.0 are entered. (See Appendices D and E.) From an estimate of yearly mileage and the cost of fuel, total discounted fuel costs over the life of the truck are determined: $14,134 for a typical truck using engines the size of the V8-8.2. (Fuel use for less-intensively used Class 6 trucks--"light 6's" below--might cost only $10,400. This distinction is important in calculating impacts on the choice of diesel versus gasoline engines, since the competition between these two types of engines is most intense for smaller and less-intensively used vehicles.)

The V8-8.2's projected share of the market in the absence of tighter regulations, about 1.3% of a projected 434,000 heavy truck sales in 1992, is entered to provide a basis for comparison.

The calculations take into account the impact of the regulations on the V8-8.2 in comparison to the impact on competing families to estimate how the baseline sales would change.

The V8-8.2 will have three added "costs" associated with its purchase that could affect its sales. First, its need for a trap and EGR will raise production costs for the engine and the trucks in which it is used. Manufacturers will have a tendency to pass these costs along if, as is likely to be the case, all competing engines face similar added costs. The ECU assumed to be added to the V8-8.2 by 1992 would probably have been added whether or not the regulations forced the issue, for advantages divorced from emissions control. Thus, the ECU's cost (and some of the fuel economy benefits that it would bring) are not included in this assessment of the effect of the regulations. Second, the trap is likely to cut its power output by about one percent, which would reduce the engine's value by about \$80. Third, and most significant, the trap and the more stringent NO_x standards will increase fuel consumption and therefore increase fuel costs. The fuel penalty attributable to the trap is one percent of total fuel usage, which would amount to about \$140. The penalty attributable to the NO_x standards would be ten times as great, at about \$1400. This penalty was calculated by taking the baseline NO_x level for this engine, subtracting almost two grams to allow for the beneficial effects of a moderate degree of EGR, and then estimating the fuel consumption increase that would be incurred in bringing emissions down to the standard by changes in injection timing. This procedure generated a penalty of 10.9%; the ECU unit is assumed to be able to reduce this penalty by one percentage point to 9.9%, and multiplying this factor by the anticipated discounted fuel costs for typical Class 6 trucks of \$14,134 yields about \$1,400.

The sum of the increased hardware costs, the two fuel penalties, and the small loss in value due to the reduction in power equals \$2,083. The impact of this regulation-induced burden on the engine's sales depends largely on how it compares to other engines in its class. Similar calculations for competing engines show that the V8-8.2 is hurt somewhat more than average: the sales share weighted average of regulatory burdens for engines in the price and power range of the V8-8.2 yield an estimate of \$1,845, or about \$240 lower. Applying an elasticity of -5.0 to this roughly three percent relative change in value drops the sales of the V8-8.2 by about fifteen percent.[1/]

1/ The loss is closer to eighteen percent after a normalization to ensure that the sum of the sales gained by one group of engine families equals those lost by the others, when total sales are held constant.

The V8-8.2 sustains further sales losses as truck sales contract. For this calculation, the average regulatory burden for Class 6-size engines is compared to the average price of a Class 6 truck--about $29,000. The average burden of $1,845 amounts to about six percent of $29,000, and the application of an estimated elasticity for trucks of -0.46 implies that sales of Class 6 trucks would fall by about three percent. Sales of the V8-8.2 are assumed to fall proportionately.

Finally, the V8-8.2 is expected to lose even more sales because Class 6 trucks would install more gasoline engines and fewer diesels. The regulatory burden falling on small diesels over the years 1987 through 1992 to reduce sales of diesel for use in Class 6 trucks by about nine percentage points: sales in the class might be 88 percent diesel in 1992 instead of the 97 percent projected in the absence of further changes in regulations. Again, sales of the V8-8.2 are assumed to fall in proportion to the reduced sales of Class 6 diesels.

Overall, the sales of the V8-8.2 would be lower by about 28 percent. Working from a baseline projection of its share of the market without the regulations, and the revenues the industry receives per sale, this reduction in sales translates into a loss of $13 million for the year. Similar calculations for the other 31 engine families examined were used to estimate the overall revenue changes for each of the five manufacturers of HDDEs.

APPENDICES: METHODS, ASSUMPTIONS, AND SOURCES

Appendix A
PRICES OF ENGINES

Engine prices are not published, but it is possible to approximate them closely enough to more than meet the requirements of this study. The Truck Blue Book[1] lists the differences in trade-in value of diesel-powered trucks with particular engines other than the standard engine, and these data can be used to compute the approximate relative retail prices of the engines.

A.1 Development of Relative Value Estimates

The 1983 edition of Truck Blue Book compares the values of one-year-old 1982 trucks with differing engines. Because diesel engines depreciate slowly, (about ten percent per year for the engines shown) the differentials are likely to be close to, though somewhat less than, the differences in prices of new 1982 trucks. These differentials for one-year-old engines, measured in 1982 dollars, are taken to be close to the differentials for new engines measured in the 1980 dollars used in the study.

A.2 Transformation of Relative Value Estimates into Absolute Value Estimates

The Truck Blue Book comparisons provide only a set of comparative engine values, not the absolute prices themselves. To find the prices, the difference in price between identically equipped new gasoline and diesel trucks has been used to find the difference between diesel and gas engines. The fact that gasoline engines cost roughly a third as much as comparable diesel engines[2] was used to find the approximate price of gasoline engines, and this was in turn

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1/ Truck Blue Book, National Market Reports, Inc., January, 1983.

2/ Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines, U.S. EPA Office of Mobile Source Air Pollution Control, 1979, p. 22.

used to fix the value of the lowest-priced heavy-duty diesel engines (those that compete with heavy-duty gasoline engines) at 1.5 times the difference between them and the price of gasoline engines. The estimated prices are shown in Exhibit H.1.

A conversation with a representative of one of the firms, who did not wish to be quoted, confirmed that this method generated a reasonably accurate range for list prices of engines, but that discounts available to fleets could result in some engines being sold for considerably less that these prices.

Appendix B
ASSIGNMENTS OF ENGINE FAMILIES TO TRUCK SIZE CLASSES

It was important for the purposes of the study to be able to match engine families with truck classes. A judgment as to which class or classes of trucks an engine is likely to be used in helps to determine how intensively it will be used, and hence the dollar impact of a given percentage increase in its fuel consumption. It also suggests which other engine families it will be competing with most directly.

Engines are not rated as being Class 6 or Class 8, but the standard engines for trucks of various classes fall into reasonably consistent horsepower ranges: engines over 230 horsepower, for example, are almost always found in Class 8 trucks, while engines under 200 horsepower are associated with Class 6 trucks. This pattern guided the process of assigning engine families to classes: in general, engines under 200 horsepower were assumed to be installed in Class 6 trucks. Those up to about 230 were assumed to be used in Class 7 trucks, and the most powerful were assigned to Class 8. Those on the borderline between classes (in horsepower, or in cost--since more expensive engines are likely to be better suited to heavier-duty use) were assumed to compete about equally for use in Classes 6 and 7, or Classes 7 and 8. Exhibit H.1 shows the assumptions made for the engine families used in the study.

Appendix C
COST PASS-THROUGH ASSUMPTIONS

It is assumed for the purposes of projecting the impact of the regulations that the manufacturers pass hardware costs along to purchasers under two conditions. First, if the increases are no greater than the increases the firm's competitors would have to make in response to the regulations, the costs will be passed along even if the hardware added does not improve the product. Second, if the added hardware adds value to the product in addition to helping to control emissions, the cost increases will be passed along even if the added costs are higher than those of other firms. These assumptions are based on the proposition that pricing decisions must meet long-term competitive pressures.

It is not assumed, however, that the firms attempt to cushion their customers from increases in operating costs by cutting prices--even if their products are more seriously affected by the regulations. It may be somewhat unrealistic to assume that an engine that is noticeably less efficient will not be discounted in comparison to other models. However, the assumption that prices will not be adjusted to account for differences in fuel efficiency is unlikely to affect projections of the firms' financial positions: so long as the firms set prices and outputs so as to maximize their profits, minor price and output differences will not change total profits appreciably. Discounts for relatively less efficient engine families could eliminate sales changes, but total revenues and net revenues would still be lower due to the price reduction.

Appendix D
DEMAND ELASTICITIES FOR INDIVIDUAL ENGINES

It was not considered practical to try to estimate the demand elasticities of each individual engine line of each manufacturer. Instead, a representative value for a typical engine line was used, based on an indirect measure of demand elasticity as seen by an engine manufacturer.

D.1 Basis for Calculation

The methodology is based on the fact that firms can maximize profits (acting independently) by choosing their markup over marginal costs to be equal to the inverse of their demand elasticity minus one: a price-taking firm seeing virtually infinite elasticity has no markup, but sets output such that price is equal to marginal cost; while the markup increases without limit as elasticity approaches one. To compare prices to marginal costs it is necessary to find the variable component in engine manufacturers' costs, and to compare this to average revenues from engine production. Because Cummins is the only truck engine manufacturer to derive almost all of its income from engine production, the calculations were performed for Cummins and generalized to the other producers--which is a close approximation so long as Cummins' products are not seen as being any more or less unique than the products of other manufacturers.

D.2 Indirect Calculation of Firm-Specific Elasticity

Calculations[1/] showed that Cummins' prices allowed for a markup of only about 20 percent over marginal costs. This implies that in Cummins' view, the demand

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1/ Regression analysis of data on Cummins' costs, profits, and output over the years 1964 through 1979 from Moody's showed that net earnings as a percentage of total revenues rose by 0.13 percentage points for each 1% increase in output. (Changes in real output were measured from an exponentially growing trend line, which fit the data extremely well.) For instance, from 2.4% of revenues at a normal level of output (as measured by the trend in output) net earnings rose to 2.53% of output at sales equal to 101% of normal levels. Total profits, then, increased by (2.53% * 101% - 2.4% * 100%), or (2.56% - 2.4%), or 0.16% of total

(continued)

for its products is not inelastic enough to allow large markups without unacceptable losses of market share: for each one percent increase in its prices (assuming the increase does not relate to an increase in quality) Cummins might expect a five percent drop in sales. Elasticities in this range might well apply for other manufacturers, whose demand elasticities could not be observed even in this indirect fashion.

D.3 Relationship of Firm-specific to Engine-line Specific Elasticity

This calculation relates strictly to increases in the prices of all of a company's products at once. Increases in the prices of one engine line out of the several sold by each company might be expected to result in even greater reductions in sales in that one line if different lines produced by the same company were close enough substitutes for each other to compete directly. However, because each company produces engine families in various power and duty ratings, which might not be close substitutes in particular uses, it seems likely that most of the competition for a particular engine family comes from similarlyrated engines made by other companies. Because of this, the measure of the elasticity of all engines produced by a firm can also serve as an approximate measure of the demand elasticity for individual engine families.

D.4 Possibility of Collusive Pricing

It could be argued that the firms do not try to maximize profits in a non-collusive way, but rather collude to raise prices above the level that would give the highest profits without colluding. It may be noted, however, that the rather low markup employed by Cummins, a leading engine producer, testifies to the unlikelihood that these prices are supported by collusion. In addition, the possibilities for entry into the diesel truck engine market by other domestic diesel engine makers, domestic gasoline truck engine manufacturers, and

(footnote continued)
revenues as revenues rose by 1%. Of each added dollar of sales, then, 16 cents are added to profits, while the remaining 84 cents represent recovery of added costs. The addition to costs is, of course, the marginal cost per dollar of output, and the markup over marginal cost is 16 cents on 84 cents, or about 19%.

foreign diesel truck engine manufacturers, would dampen the long-term attractions of collusive behavior.

Appendix E
DEMAND ELASTICITIES FOR TRUCKS

The price elasticity of demand for heavy-duty trucks used for this report is 0.46.[1] The use of this value is based on an econometric analysis of changes in heavy-duty truck prices, sales, and other factors. This analysis is described below.

E.1 Choice of Source of Estimate

Measurement of the elasticity of demand for trucks is problematic for a number of reasons, including the fact that quality and product mix changes are often confounded with price changes and that prices have not varied over a wide enough range to allow their impacts to be seen distinctly. Two alternatives to a direct statistical measurement were explored: an estimate based on the demand for trucking services--from which the demand for trucks is derived--and the reliance on an estimate used by EPA for an earlier regulatory impact analysis (on truck noise regulations). Neither of these alternatives seemed appropriate for this study. The previous EPA study employed a range of 0.5 to 0.9 which seemed to be an overestimate, made to ensure that sales impacts of the noise regulations under consideration had not been underestimated. The derived demand approach, on the other hand, led to a very small estimate of demand for trucks that seemed to be an underestimate because it neglected the possibility of using fewer trucks more intensively to transport the same loads if the price of trucks were to rise. An independent attempt to measure elasticity, on the other hand, had the advantage that it allowed the effects of changes in GNP and fuel prices on sales to be measured in the same framework.

E.2 Independent Variables

Yearly data from 1971 through 1981 on three factors expected to affect truck sales were used.

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[1] Price elasticities of demand are virtually always negative, if defined in the same way that other elasticities are defined. It is customary, though, to report them without the minus sign, since there can be no confusion as to the actual sign of the effect of increases in prices on sales.

E.2.1 Prices of Trucks

Truck prices, which affect the capital costs of truck ownership, were taken from a U.S. Department of Transportation document.[1] These data were adjusted for inflation, as well as for changes in the mix of truck classes sold. This last adjustment was necessary because there were wide swings in the proportions of trucks of different sizes, and hence different price ranges, sold during the 1970s, and the published data did not account for these changes. Therefore, the published data would show an increase in the prices of trucks sold if more Class 8s and fewer Class 6s were purchased, even if no individual truck had changed in price. The analysis used a series of price changes weighted by sales of classes having class-wide average prices taken from the same DOT publication.

E.2.2 Fuel Costs

The cost of fuel affects the operating costs of trucks, thereby affecting the profitability of the trucking industry and hence the demand for trucks. Fuel prices were taken from Monthly Energy Review. Because diesel and gasoline prices moved roughly together in the time period considered, and because gasoline prices were more easily obtained in a continuous and consistent series, gasoline prices (adjusted for inflation) were used for the analysis though both fuels are theoretically important in explaining truck sales over the period.

E.2.3 Business Cycles

General business conditions might be expected to influence the demand for trucks both by changing the expectations of business volumes (and thus the demand for trucking services) over the near term, and also by placing a premium on liquidity, thereby discouraging expenditures on long-lived capital assets like trucks. The data series used in the analysis was the real GNP series provided by the Department of Commerce, lagged by one year. It was found that GNP

1/ Transportation System Descriptors Used in Forecasting Federal Highway Revenues, Federal Highway Administration, U.S. Department of Transportation, 1981.

lagged one year fit the data better than current GNP, which is understandable given the facts that drops in business activity take some time to be noticed and confirmed, plans take some time to be changed, and there is often a considerable lag between the ordering and delivery of heavy trucks. This last circumstance may be explained by the fact that the range of specifications open to truck purchasers is large enough to make it impractical for most truck assemblers to have finished trucks available for delivery; instead, trucks are assembled only after they have been ordered.

E.3 Dependent Variable

The dependent variable was the sum of heavy truck registrations for Classes 6,7, and 8, for the years 1971 through 1981.

E.4 Results of Demand Analysis

The estimated regression equation was:

$$S = 550.9 - 1.33\,P_f - 1.58\,P_t + 15.6\,\Delta GNP \qquad n = 11 \qquad R^2 = .84$$

where

S	=	Annual Sales, Classes 6,7, and 8, in thousands;	mean = 309
P_f	=	Real fuel price index	mean = 110
P_t	=	Real truck price index, adjusted for changes in class mix	mean = 88.9
ΔGNP	=	Lagged percentage changes in real GNP	

A high proportion of the variation was explained, as indicated by the R^2 of 0.84.

E.5 Interpretation of Truck Demand Results

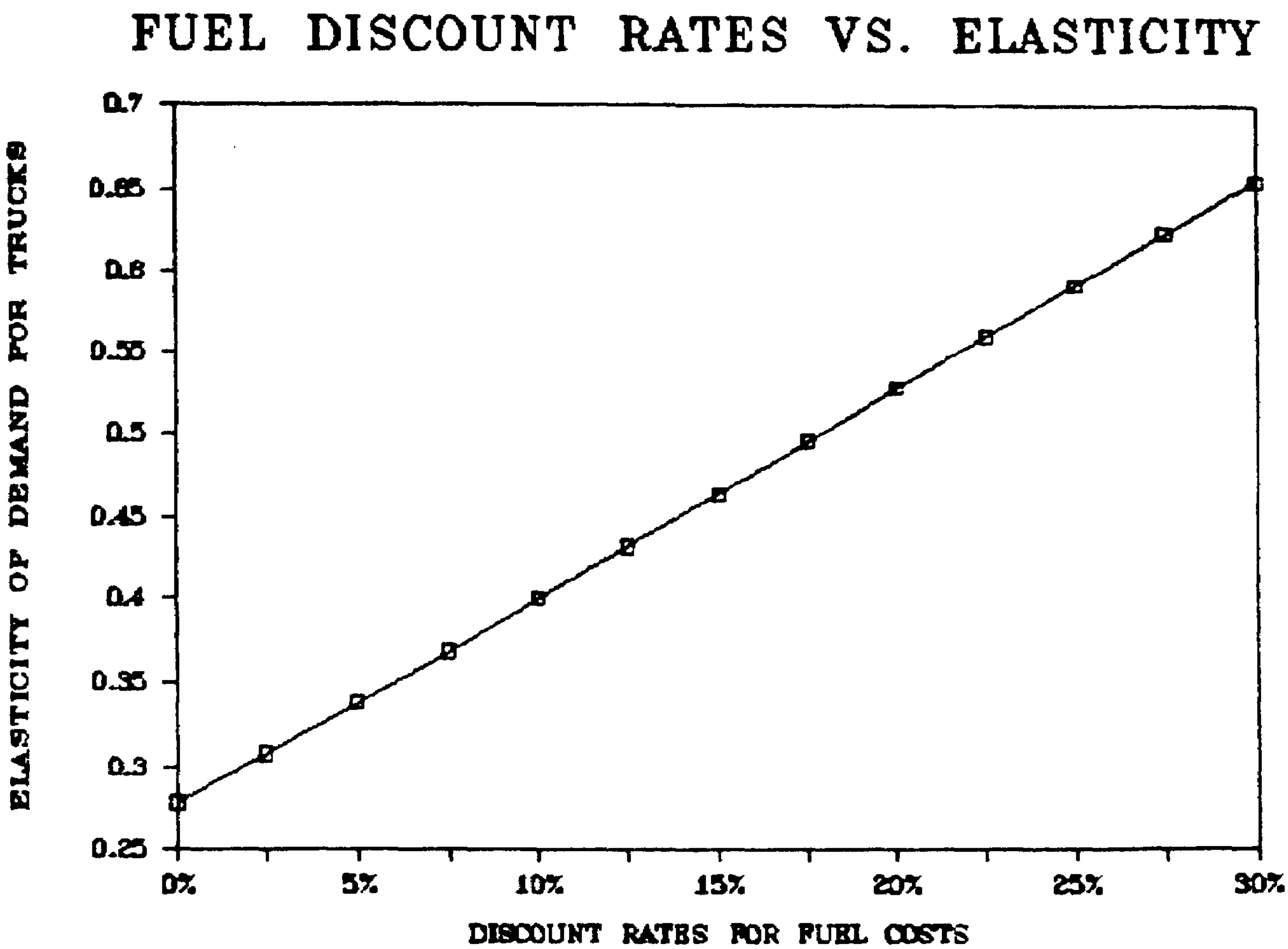
The strong cyclical nature of truck sales is highlighted by these results. In the range of the variables studied, a 1% drop in GNP is seen to produce a 5% drop in sales of trucks in the following year. Fuel costs were also seen to influence truck sales in the expected direction: with each one cent change in the price of fuel, sales dropped by 0.46%. This may be translated into its equivalent price elasticity if a discount rate is chosen and if the lifetime distribution of fuel expenses for trucks, compared with the prices of trucks, are known. At a 10% discount rate this impact is the equivalent of a first-cost demand elasticity of 0.4; for higher discount rates (closer to internal rates of return and the cost of capital) such as 25%, the elasticity is a higher 0.6. This relationship is shown in Exhibit E.1.

Given the information shown in Exhibit E.1, and a reliable estimate of the *price elasticity of demand for trucks, it would be possible to calculate the* discount rate applied to fuel costs by marginal truck consumers--those most sensitive to changes in fuel costs. The regression analysis shows an elasticity of approximately 0.46, which would imply a discount rate of about 15% per year. While no t-statistic was computed for the coefficient on which this was based, it should be said that its sensitivity to small changes in the specification of the regression equation suggested that a wide confidence band be employed with the estimate.

Alternatively, by choosing a reasonable estimate of the discount rate applied to operating costs, some light may be shed on the price elasticity of demand for trucks using the information on the impact of changes in fuel costs on truck sales. Such an approach would suggest that the elasticity of demand is well below unity, but greater than 0.3. These calculations are consistent both with the estimate from the analysis done for this study, and with the estimates used previously by EPA.

It should also be noted that the changes in operating costs found in this analysis affected the entire truck fleet because they resulted from increases in the costs of fuels. The cost increases important for this study, however, affect only new trucks. To some extent, therefore, the short-term elasticity of demand will be greater for the operating cost changes considered in this study, as repairs done on older trucks will be substituted for purchases of new trucks with cleaner but less efficient engines.

Exhibit E.1

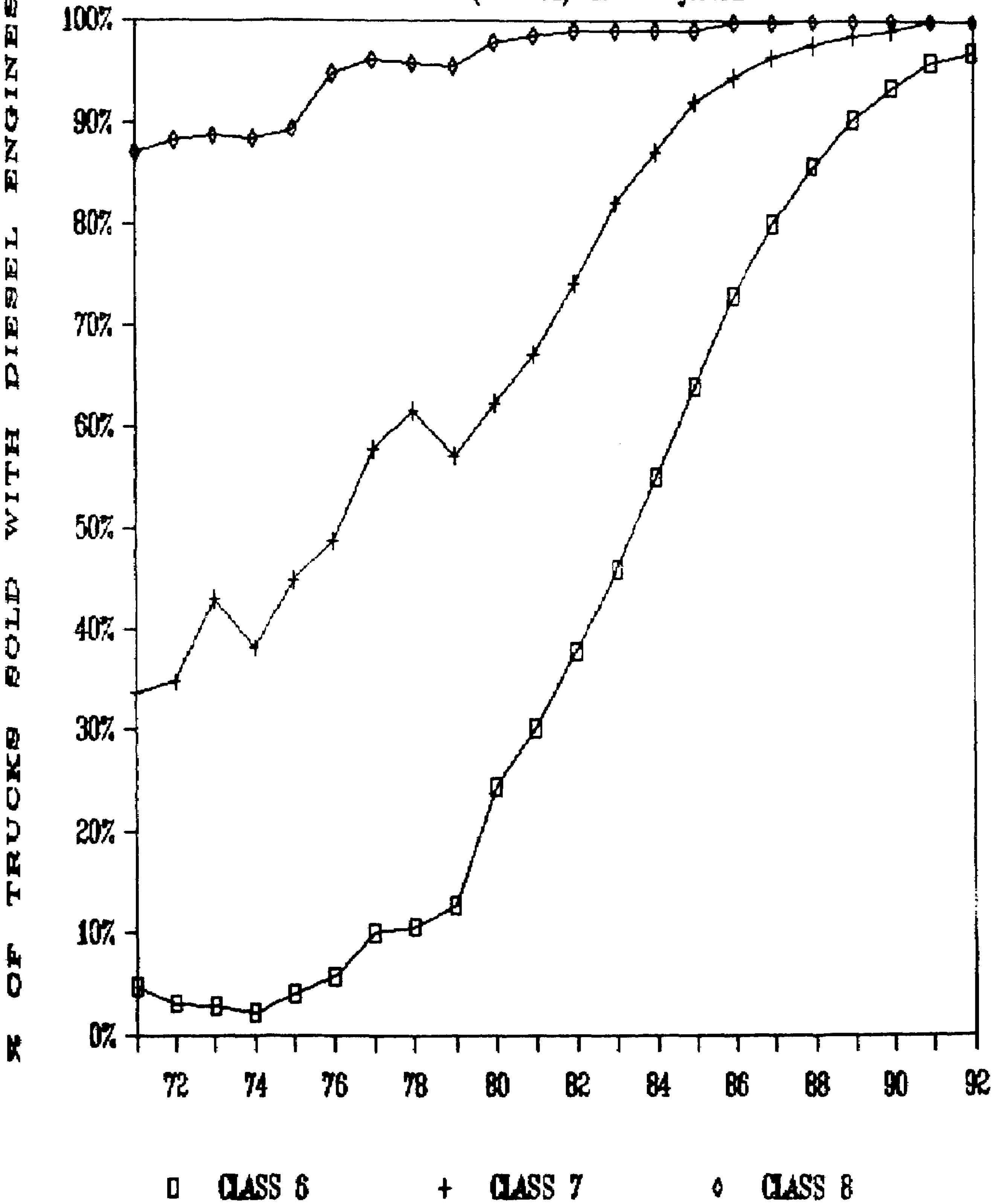


FUEL DISCOUNT RATES VS. ELASTICITY
ELASTICITY OF DEMAND FOR TRUCKS
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0%
5%
10%
15%
20%
25%
30%
DISCOUNT RATES FOR FUEL COSTS

Exhibit I.1

DIESELIZATION BY CLASS

Historical (to 1981) and Projected



Appendix F
FUEL CONSUMPTION IMPACTS OF NO_x CONTROLS

F.1 Source of Estimate of Penalty at Varying NO_x Standards

The actual magnitude of the consumption penalties resulting from various NO_x standards is unknown, and controversial. This report bases its estimate of the magnitude on a National Academy of Science Report, NO_x Emission Controls for Heavy Duty Vehicles: Toward Meeting a 1986 Standard,[1] and work done by ERC for EPA on the feasibility and costs of NO_x and PM regulations for trucks. The former source was used to estimate the fuel economy impacts that the regulations would have on engines if only relatively unsophisticated NO_x control techniques were used, while the work done by ERC was used to factor in the beneficial effects of more modern techniques such as advanced charge-air cooling and electronic control units.

In the NRC study, it was reported that an engine that would show no fuel consumption increase in order to reach an emissions level of 8 grams (one having baseline emissions of 8 grams) would suffer a 2.5% to 4% increase if its emissions were forced to 6 grams; 7% to 12% at 4 grams, and 15% to 20% for a target of 2 grams. The upper part of the range of fuel consumption increases would be more likely to be seen if less sophisticated emissions reduction techniques were used. For this analysis, we fit a function to approximate the relationship between the target and the fuel consumption penalty for an engine with uncontrolled emissions of 8 grams. This "8 gram" formula takes the following form.

$$p = a + b \ln(e/(2*t))$$

where p is the increase in fuel consumption in percent;
a is equal to 17.9;
b is equal to 17.3;

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[1] NO_x Emission Controls for Heavy Duty Vehicles: Toward Meeting a 1986 Standard, Motor Vehicle Nitrogen Oxides Standard Committee, Assembly of Engineering, National Research Council, National Academy of Science, 1981.

e is the base of natural logs; and

t is the target for NO_x emissions in grams per brake horsepower-hour.

This function closely approximates the upper bound on the NAS relationship, at least in the range of potential NO_x targets, and thus represents the NO_x/fuel economy tradeoff for an engine with typical baseline emissions if no advanced emissions control techniques were available. Estimates of changes in fuel consumption for particular engines families, each with an individual combination of baseline emissions and control techniques, were made by shifting the function described above toward higher or lower fuel consumption penalties at given NO_x targets.

Influences of Baseline Emissions and Advanced Technologies on Changes in Fuel Consumption

The increases in fuel consumption at various NO_x emissions targets predicted by the function described above can be expected to be less serious for engine families that were lower-than-average emitters before the imposition of stringent standards, and can also be expected to be lower for engines that adopt advanced control technologies that are able to cut emissions to some degree without increasing fuel consumption.

F.2 Method of Relating Baseline NO_x Emissions to NO_x Penalties

For this report, it is assumed that 49-state engines[1]/ that had lower NO_x emissions when tested in 1982 will also have lower regulation-induced fuel consumption penalties. This assumption is supported by EPA in Ann Arbor.[2]/ These engines are likely to be inherently cleaner, and, for a given NO_x target, have lower excess emissions to eliminate. If a given engine has baseline emissions of only 6 grams, it will suffer no fuel penalty at a NO_x target of 6 grams--since no changes will have to be made in its design or operation to meet the standard.

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[1]/ Engines certified for sale in California, which have already been modified to meet stringent NO_x standards, are not assumed to fit into the same relationship.

[2]/ Conversation with Tim Cox, U.S. EPA Ann Arbor.

An engine with a higher baseline emissions level--8 grams for example--will suffer increased fuel consumption of about 4 percent according to the function described above. Thus, the "6-gram baseline engine" would hold a four percentage point advantage over an "8-gram baseline engine" at a target of 6 grams. In this report, the assumption is made that this 4 percentage point advantage holds at other NO_x targets as well. Thus, the effect of the lower baseline emissions is to shift the function relating fuel consumption increases to the target downward by a constant amount.

Treatment of Advanced Emissions Control Techniques

Some techniques of emissions control are able tc reduce emissions without adversely affecting fuel consumption. These techniques include turbocharging, charge air cooling, advanced charge air cooling, EGR, and the use of ECUs. It has been assumed for this study that the first four of these techniques effectively lower the baseline emissions of the engine families to which they are added, and that the ECU directly lowers the fuel consumption by an amount dependent on the stringency of the target. The degrees to which each technique is assumed to change emissions, and the bases for the assumptions, are presented below.

Turbocharging: One engine family, the Caterpillar 3208, is expected to be replaced by a turbocharged version of the same engine as a result of the regulations. A comparison of the emissions of the turbocharged and non-turbocharged engines was the basis of the assumption that the turbocharger could reduce NO_x emissions by about 5 percent.

Charge air cooling: Comparisons among several similar engine families with and without intercooling or aftercooling led to the assumption that, on average, charge cooling reduces baseline NO_x levels by about 6 percent.

Improved Charge air cooling: ERC's Christopher Weaver's report on the effects of NO_x regulations was the source of the assumption that improvements in intercooling (using a circuit of cooling water or air separate from the engine's

radiator, to lower the temperature of the charge further) would reduce baseline emissions by fifteen percent (though even greater reduction might be possible)
EGR: Comparisons show that quite substantial reductions in NO_x emissions--in the range of 40%--can be achieved using EGR to a sufficient degree. According to Weaver's report, and other sources, the use of EGR would be kept moderate to reduce some of its anticipated problems. For this report, it has been assumed that this moderate use of EGR would reduce baseline emissions by 20 percent.

ECU: Comparisons of the tradeoff between NO_x emissions and fuel consumption for a number of experimental engines with and without electronic control units, reported by Weaver, provided the basis for an assumption about the ECU's influence on the tradeoff. It is assumed that the addition of these units would shift the emissions/fuel tradeoff curve down by 3 percentage points if the NO_x target were about 6.0 grams, but only 1 percentage point if the NO_x target were at or below 4.0 grams.

Average Fuel Consumption Increases

The application of the methodology described above, in which a general emissions/fuel consumption tradeoff curve is shifted according to the characteristics of each engine family considered, resulted in fairly close agreement with independent assessments of the near- and intermediate-term fuel economy effect of the regulations. The table below compares the calculated fleet-wide average increase in fuel consumption that would result from NO_x regulations to estimates by ERC:

TIME FRAME	NO_x STANDARD	FUEL CONSUMPTION INCREASE	
		SCI	ERC
Near	6.0	4.5%	3.5% to 5.5%
Intermediate	6.0	1.5%	0% to 1.5%
Near	4.0	12.0%	10% to 15%
Intermediate	4.0	7.1%	4% to 8%

F.3 Adjustment for the Difference Between the Standard and the Target

The estimation procedure described above is couched in terms of the target for NO_x emissions, not the standard. Because manufacturers will have to aim below the standard in order to ensure that a high proportion of their engines will meet the standards (in the absence of an averaging provision for NO_x emissions) it has been assumed that the target for 4.0 gram NO_x standard will be 3.5 grams, and that the target for the 6.0 gram standard will be 5.4.

Appendix G
FUEL CONSUMPTION IMPACTS OF PARTICULATE MATTER CONTROL

It may be that traps will hurt fuel consumption in engines with high baseline emissions more than in those with low emissions, because of the need to use a larger trap (causing more back-pressure on the engines) or the need to burn off the accumulated soot more often (using more fuel for that purpose). However, for this report, we relied on estimates made by Weaver of ERC that the most promising trap technology would increase fuel consumption by 0.75 percent for the largest trucks, and by 1.0 percent for smaller trucks.

Appendix H
ENGINE FAMILIES CONSIDERED

Exhibit H.1 shows the engine families analyzed, and the data concerning them as used in the study. Shown are the baseline NO_x values, calculated fuel consumption penalties, estimated relative prices, approximate baseline share of unit sales, and class assignments. Notes following the table describe some assumptions made in assembling the data.

Exhibit H.2 summarizes the changes in the engines that are assumed to be made in the near and the intermediate term in order to comply with the standards.

Exhibit H.1
ENGINE FAMILY DATA

ENGINE FAMILY	HP Range[10]	Assigned Class[11]	NO_x Level[12]	Estimated Price[4]	Estimated Market Share[13]
Caterpillar					
3208	160-210	6,7	8.39	$10335	13.5
3208 T	175-250	7	8.14	$11785[8]	1.8
3306	270	7,8	8.06	$16322	0.2
3406	325	8	8.49	$18588	0.8
3406	350-400	8	8.23	$22442	3.5
3408	450	8	6.53[5]	$26010	0.5
					20.3%
Mack[1]					
10 (EM9-400)	392-450	8	7.8	$21595[6]	0.04
11 (EM6-237)	235	7,8	8.4	$17220	4.4
12 (E6-350)[2]	285-350	8	8.6	$20505	4.7
13 (E6-350)[3]	300-350	8	7.4	$21595[6]	0.1
					9.24%
IH					
DT-466B	180-210	6,7	8.16	$ 8130	16.8
9.0 liter	165-180	6	7.75	$ 8130	1.7
DTI-466B	210	6,7	7.66	$ 8630[7]	1.1
					19.6%
DD-A (GM)					
V8-8.2	130-165	6	8.20	$ 8130	1.3[9]
V8-8.2 T	160-205	6,7	8.17	$ 9590	1.2[9]
4L-53T	170	6	7.67	$ 8130	1.3
6V-53T	225	7	8.46	$11435	1.0
6L-71N	260-275	7,8	8.26	$14770	1.9
8V-71N	245-316	7,8	7.73	$15960	0.9
6V-92TA	325	8	9.88	$15800	3.9
8V-71TA	305-318	8	8.16	$18355	1.1
8V-92TA	355	8	9.62	$21635	2.1
6V-71TA	210-250	7,8	8.32	$16840	0.9
6L-71T	260-275	7,8	9.61	$16840	0.8
					16.5%
Cummins					
091	220	7	8.22	$15160	0.2
092A	293	8	8.28	$17555	12.1
092E	400	8	8.71	$23755	20.0
172C	350	8	7.37	$16660	0.3
192B	450	8	8.12	$25900	0.03
193	600	8	9.7	$32085	0.7
221	216	6,7	8.81	$ 8130	0.03
222	225	7	7.58	$11430	1.1
					34.46%

1/ EPA engine family designations.

2/ Includes EM6-285 engines.

3/ Includes EM6-250,275, and 300 engines.

4/ Method for generating price estimates is described in Appendix A.

5/ The low value for this engine suggests that it may have been set up to pass California emissions standards, in which case it would not be a valid baseline emissions level for this study.

6/ Values for these particular low-volume engines was unavailable. Values used are those for highest value Mack engines provided; these are likely to be underestimates.

7/ Increased value of intercooler for this engine was not clear from data in Truck Blue Book. Estimated premium of $500 was based on EPA's estimate of the cost of charge cooling, with a mark-up added for overhead and profit.

8/ Increased value of turbocharger for this engine was not clear from data in Truck Blue Book. Estimated premium of $1460 was based on difference between DD-A's V8-8.2 and V8-8.2 T engines.

9/ These models were introduced since market share data was collected and published. Estimate of share was made with some guidance from EPA, Ann Arbor.

10/ Horsepower ranges shown are the ranges of horsepower among the models tested.

12/ Baseline NO_x levels for the engines are taken from Federal Certification Test Results for 1982 Model Year. Values used are straight averages of NO_x levels for various engines tested within a given family, excluding engines with NO_x levels below 6.0 grams. These were excluded because of the very high likelihood, according to Tim Cox of EPA, Ann Arbor, that they were set up to pass California emissions standards. Because this means that they were already subjected to NO_x controls, they do not represent accurately the baseline (uncontrolled) NO_x emissions levels of the engine family.

13/ Market shares are based on Summary and Analysis of Comments on Proposed Heavy-Duty Engine Emission Regulations, p. 220, for shares within firms and data from the Motor Vehicles Manufacturers Association for manufacturer shares. These were adjusted for expected gains in the diesel share of smaller trucks, resulting in greater sales for smaller engines. Changes in model designations and availability, in addition to changes in consumer needs and tastes render these estimates only approximate.

Exhibit H.2
TECHNOLOGICAL STEPS ASSUMED TO BE TAKEN

ENGINE FAMILY	Turbo-Charger	New Piston	Charge Cooler	Improved Charge Cooler	Moder-ate EGR	ECU	Injector Changes	Small Trap	Large Trap
Caterpillar									
3208	n,i		n,i	n,i	i	i		i	
3208 T			n,i	n,i	i	i		i	
3306					i	i		i	
3406			n,i	n,i	i	i			i
3406					i	i			i
3408					i	i			i
Mack									
10 (EM9-400)		n,i		n,i	i	i	n,i		i
11 (EM6-237)		n,i		n,i	i	i	n,i	i	
12 (E6-350)		n,i		n,i	i	i	n,i		i
13 (E6-350)		n,i		n,i	i	i	n,i		i
IH									
DT-466B			n,i	n,i	i	i		i	
9.0 liter				n,i	i	i		i	
DTI-466B				n,i	i	i		i	
DD-A (GM)									
V8-8.2					i	i		i	
V8-8.2 T			n,i	n,i	i	i		i	
4L-53T			n,i	n,i	i	i		i	
6V-53T			n,i	n,i	i	i		i	
6L-71N					i	i		i	
8V-71N					i	i		i	
6V-92TA				n,i	i	i			i
8V-71TA				n,i	i	i			i
8V-92TA				n,i	i	i			i
6V-71TA				n,i	i	i		i	
6L-71T			n,i	n,i	i	i		i	
Cummins									
091					i	i		i	
092A			n,i	n,i	i	i			i
092E				n,i	i	i			i
172C			n,i	n,i	i	i			i
192B			n,i	n,i	i	i			i
193				n,i	i	i			i
221					i	i		i	
222			n,i	n,i	i	i		i	
Assumed Cost[1]/	$900	$5	$134	$82	$20	$202	$50	$445	$1618

"n" indicates use in the near term--1987 through 1989.
"i" indicates use in the intermediate term--1990 through 1992.

1/ Costs were taken from EPA reports on compliance with regulations involving HC, CO, NO_x, and particulate matter including Regulatory Analysis and Environ mental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines, Draft Regulatory Analysis, Environmental Impact Statement, and NO_x Pollutant Specific Study for Proposed Gaseous Emission Regulations for 1985 and Later Model Year Light Duty Trucks and 1986 and Later Model Year Heavy Duty Engines, RIA to October 15 1984 Proposed Rulemaking re: Gaseous Emissions Regulations for 1987 and Later Model Year Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Engines; Particulate Emission Regulations for 1987 and Later Model Year Heavy-Duty Diesel Engines; and Particulate Control Technologies and Particulate Emissions Standards for Heavy Duty Diesel Engines (Draft), Energy and Resource Consultants Inc., February, 1984 for costs of partuculate traps (markup for dealers was subtracted).

Costs for charge coolers, improved charge coolers, exhaust gas recirculation, and electronic control units may be unreasonably low. This is not a serious problem, however, since all of these technologies except EGR are likely to be adopted for reasons other than emissions control in any case. Even if actual costs for EGR are many times the most recent EPA estimate of $20 (an earlier EPA document used $100) the hardware costs attributable to the regulations are not likely to be significant.

EGR and traps are assumed to be used only in the intermediate term, and only under some regimes. EGR would be used only if a stringent NO_x standard were set, and traps would be used only to the extent described in Exhibit 3.3.

Appendix I
ANALYSIS OF DIESELIZATION

For the purposes of the report, it was necessary to project diesel penetration in the absence of the regulations and to discern the impact on these baseline projections that would result from changes in the advantages of diesel engines.

I.1 Diesel Penetration as a Diffusion Process

Diesel penetration among the three classes of trucks in the study was--like diesel penetration among locomotives, and other new types of equipment--modeled as a diffusion process. Students of these processes have found that the spread of innovations, even those with marked advantages over their competitors, can be slow: the economic system appears to adjust to improved techniques over a period of years. The pattern of cumulative adoptions has been seen to approximate a logistic function, a curve which rises slowly at first, accelerates, and then begins to rise more slowly at it approaches an asymptote or saturation point. The inherent advantages of the innovation in the eyes of its potential users influences both the rate at which the degree of penetration of the innovation proceeds along the diffusion curve, and the level of acceptance it can ultimately reach.

It may be predicted that the magnitude of the economic advantages of the diesel truck engine over the gasoline engines will influence the progress of its diffusion. Analysis of past changes in dieselization rates in comparison with economic factors allows the strength of the relationship between economic factors and penetration to be estimated. This estimate in turn makes it possible to project the impacts of regulatory changes on future degrees of penetration.

Economic factors might influence both the ultimate degree to which diesels penetrate the heavy-duty truck market and the speed with which this occurs. For this study the simplifying assumption was made that diesels would ultimately be the overwhelming choice for all heavy-duty trucks.[1/] The method for exploring the effect of economic factors on the rate of approach to complete dieselization is described below.

I.2 Model Used to Forecast Diesel Penetration

The model used to project diesel penetration over time has the following form:

$$p_t = \int_{i=1}^{t} (p*(1-p)*n*a) \quad dt$$

where

p = diesel penetration--proportion of purchasers specifying diesel engines;

n = net economic advantage of diesel; and

a = speed-of-adoption parameter.

That is, the penetration (or proportion of users buying diesels) at any time is equal to the sum (or integral) of all changes in that penetration in the past; and the changes are proportional to the net economic advantage of diesels (counting their fuel economy advantages, and their initial cost and other disadvantages); times a parameter that determines how quickly penetration occurs, all other things equal; times p*(1-p). The factor p*(1-p) accounts for the fact that diffusion of an innovation takes place more slowly both at first (when p is near zero) and also as the innovation's saturation level is reached (when 1-p is near zero, since in this analysis the saturation level is assumed to be 100%). The parameter "a" --the slope parameter--was estimated by examining the effects of past changes in the economic advantages of diesel on changes in diesel penetration. The one factor that has changed dramatically enough in

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1/ This assumption was based on analyses by Volvo and International Harvester showing that pay-back periods for diesels even in smaller heavy-duty trucks, even if regulatory impacts were significant, would be very rapid. These studies are presented on page C-1 of The Effects of Potential EPA Regulations on the Heavy Duty Vehicle Industry, Sobotka and Company for U.S. EPA, May, 1982.

the past to allow an estimate to be made of its impact on diesel penetration is the real cost of fuel. Accordingly, changes in the degree of diesel penetration for the three largest classes of trucks over the years 1971 to 1981 were regressed against the real cost of motor vehicle fuel. Regressions showed that the fuel cost variable explained a significant proportion of yearly variations in diesel penetration (with less than a two percent chance that the results occurred by chance, using a one-tailed t-test).

Translating this estimate of the effect of fuel costs on diesel penetration into an estimate of the effect of more general changes in the economic advantage of diesels on penetration involved calculating the dollar changes in the net economic advantage of diesels caused by a given change in the cost of fuel. This in turn required estimates of the number of gallons of fuel used by trucks of various classes over their useful lives, discounted to account for the fact that fuel savings in the future are not weighted as heavily as expenses in the present. The results of these calculations allowed the specification of the following formula for yearly changes in diesel penetration:

Change in p = (p*p-1)*n*.506

where n = d - changes in diesel costs due to regulations; and

d = $ 1987 for Class 6;
$ 3751 for Class 7; and
$ 5647 for Class 8.

These figures have taken into account the reduction in the advantages of diesels caused by the erosion in the price advantage previously held by diesel fuel. No attempt was made, however, to place dollar values on any possible changes in diesel engine performance or durability in the future.

I.3 Baseline Projection of Dieselization

This formula allowed a projection of the degree of dieselization for the years 1982 through 1990, for the three classes, as shown in Exhibit I.1 Note that the formula projects virtually complete diesel penetration for the largest classes by the time the regulations go into effect, indicating that any major changes in dieselization caused by the regulations would fall on manufacturers of Class 6 engines.

Actual figures for 1983, the most recent available, show that the method for projecting diesel pentration worked well for Class 6 trucks: the actual figure for that year was 40 percent, as compared to the predicted 46 percent. Diesel penetration among Class 7 trucks, however, was significantly lower in 1983 than was projected on the basis of data through 1981: 60 percent compared to a projected 82 percent. This slowing of the dieselization process may be reversed in the future. If it is not, however, it would mean that gasoline engines will be more competitive with diesel engines in larger trucks than they seemed a few years ago. The regulations could then have a greater impact on diesel penetration than is indicated by this report. Even in that case, however, the impact on the rate of Class 7 dieselization is not likely to be greater than the impact on Class 6 dieselization, described in Section 4.5.

Appendix J
CAPITAL COSTS

Some of the costs associated with compliance with the regulations are fixed in that they do not depend on the number of engines manufactured. These costs include research and development and certification expenditures. Differences in these costs between manufacturers and engine families are not likely to be reflected in prices of products (since marginal costs are not affected by changes in fixed costs), and have therefore been left out of the study's analysis of the relative impacts of regulations on the sales of the HDDE manufacturers.

The magnitude of these expenses are likely to be small on a per-unit basis. Total costs were estimated by EPA 1/ to be $107.2 million for the years 1985 through 1992. This amounts to 13.4 million per year, over an average of more than a third of a million units per year (by EPA's estimate 1/). On a per unit basis, then, the fixed costs amount to only about $40 per engine or truck. Even if engine producers were forced to absorb all of these costs, then, they would not be affected noticeably. Economic theory suggests that, to the extent that these costs affect the average total cost of production of engines by an efficient producer, they will be passed on to purchasers of engines and trucks. The financial position of the industry as whole would not, therefore, be affected at all except to the very small degree that truck sales were depressed by the slight (less than a tenth of a percent) increase in prices.

1/ Near-term cost of NO_x and PM regulations were estimated to be $9.3 and $19.7 million, respectively; intermediate-term (after 1989) costs for controlling these pollutants were estimated at $28.7 and $49.5 million. These figures total $107.2 million. These estimates, and estimates of truck sales, were taken from the RIA to October 15 1984 Proposed Rulemaking re: Gaseous Emissions Regulations for 1987 and Later Model Year Light-Duty Vehicles, Light-Duty Trucks, and Heavy-Duty Engines; Particulate Emission Regulations for 1987 and Later Model Year Heavy-Duty Diesel Engines.

Appendix K

ASSESSMENT OF MARKET VALUATION OF CHANGES IN HORSEPOWER

The analysis of the impacts of PM regulations attempted to account for the effects that traps are likely to have on the power output of the engines installed along with the traps. The traps absorb a small amount of the engine's power, since their filtering action partially blocks off the exhaust stream. Weaver of ERC surmised that the reduction in power would be about as large as the reduction in fuel efficiency caused by the traps--between 0.75% and 2.0%, depending on the type of trap and its application. Weaver noted that this reduction in horsepower would be too small to be noticeable. So long as truck purchasers knew of the reduction in power, however, we see no reason why it would not reduce their assessment of the value of the engine affected. We assumed that the horsepower loss due to the traps would be valued at the same rate as the horsepower is valued generally, and began to investigate the market relationship between horsepower and engine prices.

A simple regression analysis provided convincing evidence that engine prices are roughly proportional to rated horsepower. The fitted equation, illustrated in Exhibit K.1 along with the data points, is show below:

$$P = -\$370.781 + 57.723 * HP$$
$$(-0.323) \quad (15.319)$$

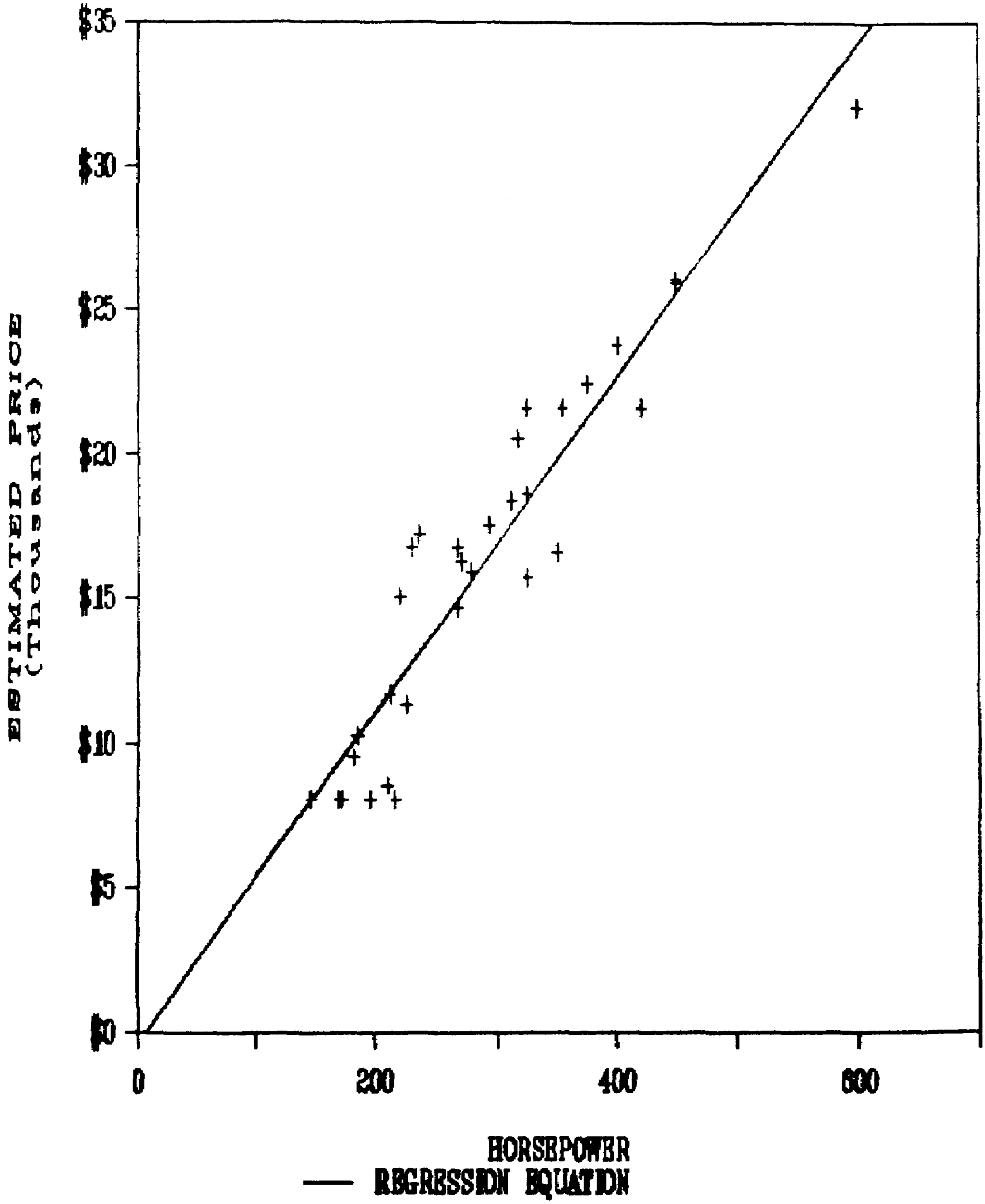
$n = 32$ $R^2 = 0.885$ t-statistic in parentheses

where P = estimated retail price, derived as described in Appendix A, and
HP = midpoint of advertised range of rated horsepower.

The regression shows that horsepower differences explain a high proportion of price differences. This analysis was used as the basis of the assumption used in the study that a one percent decrease in horsepower is equivalent to a one percent decrease in the value of the engine, a relationship that closely approximates the fitted relationship.

Exhibit K.1

RELATIONSHIP OF POWER TO PRICE



This relationship was used not only for estimating the effects of traps on performance, but also for one significant special case. The Caterpillar 3208 is likely to be dropped due to the regulations, leaving only the 3208 T, the turbocharged version of the engine, at the lower end of Caterpillar's line. This situation has been treated analytically as though a turbocharger is being added to the naturally-aspirated 3208 in order to reduce emissions. Since competing engines will not have to add turbochargers, it would be difficult for Caterpillar to pass the costs of this added hardware along to its customers if the sole value of the turbocharger were that it could reduce emissions.

The turbocharger adds power as well, however, and this added power is likely to have some value to purchasers. Current users of the 3208 engine probably do not value increased horsepower to the same degree as most HDDE users, it can be argued, since they have chosen not to pay extra for added power. It has been assumed, for lack of more specific information, that the increased horsepower of the turbocharged version is worth half as much, per horsepower, as the $57.72 per horsepower measured for the market as a whole. The increased value of the engine, estimated to be about $717, is assumed to permit Caterpillar to pass along the increased costs of producing the 3208 with a turbocharger without significant losses of sales.