Analysis of gross polluter cutpoints based on in-use vehicle inspection and maintenance test data in California

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Abstract

Emission cutpoints are used to classify vehicles as "gross polluters" in inspection and maintenance (I/M) testing in the United States. In this study, we use recent data from California I/M tests to examine how sensitive populations of "gross polluters" change as cutpoints are modified. Using statistical analyses of emissions test data, we identify a variety of scenarios that have the potential for efficiently removing a significant portion of the exhibited emissions while minimizing the number of vehicles that are classified as "gross polluters" and required to undergo costly repairs. For each scenario, we compute the resulting vehicle populations and impact on emissions. The conclusions of the research provide support for previous findings that suggests that: 1) a "gross polluting" vehicle for one pollutant, such as carbon monoxide (CO), may not necessarily be a "gross polluter" for another pollutant, such as oxides of nitrogen (NOx) and 2) each of the existing required I/M tests yield similar results and it may not be efficient to use both tests in the identification of gross polluters.
Keywords: gross polluter, gross emitter, emissions testing, inspection and maintenance programs.

1 Introduction and study motivation

The State of California defines gross polluters (also commonly known as a "gross emitters") as those vehicles responsible for more than half of all mobile contributions to smog (BAR, 2003). In general, this results in about 10-15% of the vehicle population being identified as gross polluters. The definition of a gross polluter is based strictly on the 50% of contribution criteria, and millions

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of Californian motorists are subjected to I/M tests each year based on this definition. The purpose of this research is to explore the implications of adjusting some California's gross polluter cutpoints using a variety of different scenarios. Additional motivation for this research is to define cutpoints that capture sufficient numbers of gross polluters to ensure that California meets its air quality goals.

2 Literature review

A literature review indicates that the definition of a "gross polluting" vehicle as well as the emissions levels ("cutpoints") at which vehicles are identified have been inconsistently defined from study to study with little justification provided [1]. For example, in 1994 Slott [2] identified "super emitters" as vehicles that produced 150 g/mi or more of CO or 10 g/mi or more of HC, nearly two orders of magnitude more pollution than new vehicles, but the basis of this definition is not clear. In 1995, Lawson [3] defined gross emitters as vehicles emitting 113 g/mi or more of CO and 28 g/mi or more of HC, and referenced Knapp [4]as the source of his definition. A thorough review of Knapp's work, however, reveals that these parameters were never specified [1].

While Wayne and Horie [5] were among the first to identify outlying vehicle emissions due to a fraction of the fleet and Stedman [6] characterized "gross polluters" as being the 10% of vehicles responsible for 50% of carbon monoxide emissions, today contemporary I/M programs still do not have well-documented justification for identifying cutpoints. Recent work at CARB indicates that gross polluters are initially defined as vehicles exceeding twice the new car Federal Test Procedure (FTP) standard; the definition is then modified to identify a fixed error of commission (i.e., a "false failure" rate) [7, 8]. While BAR establishes cutpoints to avoid an excessive number of false failures, there are no existing goals to identify gross polluting vehicles (i.e., "correct failures") [9]. This study fills the gap in the literature by using available data to empirically define "gross polluting" vehicles, establish cutpoints, and evaluate their effectiveness.

3 Data description

The data used in this analysis come from one month of California State inspection and maintenance (I/M) testing data collected in October of 2002 by the Bureau of Automotive Repair (BAR). The data set contains 816,326 valid test observations, each of which has one of two pairs of emissions (tailpipe) tests used to measure exhaust emissions (BAR, 2003). When vehicles are brought in for testing, either a pair of "loaded," acceleration simulation mode (ASM) tests are conducted or a pair of "unloaded," two-speed idle (TSI) tests are conducted on each vehicle. In the loaded ASM tests, vehicles are placed on a dynamometer and run first at 50% of the maximum engine load encountered on the federal test procedure (FTP) at 15 mph (known as an "ASM5015" test), and then at 25% of the maximum engine load encountered on the FTP at 25 mph (known as an "ASM2525" test). If a vehicle cannot be tested on a dynamometer, a pair of two

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speed idle (TSI) tests is performed. In the TSI tests, emissions are measured while the vehicle is at 2500 rpm (known as a "TSI2500" test) and at idle usually between 400 and 1250 rpm (known as a TSI Idle test). While all of these tests are conducted the engine load (in rpm) is simultaneously recorded with emissions measurements.

4 Analysis methods

A vehicle passes the inspection if its measured emissions are less than a specified regulated level or "cutpoint," and the emissions "cutpoints" for each vehicle vary, based on the vehicle type, size, and weight groupings as well as the different emissions tests (ASM 5015, ASM 2525, TSI 2500, TSI idle). In this section, we briefly discuss how we compute the cutpoints we use in the first part of the analysis and then we discuss each of our analysis scenarios in which cut-points are varied.

4.1 Identifying gross polluting vehicles

The I/M data contain tailpipe test measurements and overall emissions test results (i.e., pass, fail, failed gross polluter, or aborted). The data do not explicitly provide an explanation as to which pollutant(s) for which a vehicle was labelled a gross polluter. To identify each individual gross polluter, the tailpipe measurements had to be compared to the existing gross polluter cutpoints for each pollutant.

The emissions cutpoints were calculated for each vehicles in the dataset can be calculated using the relationships defined by BAR in the emissions standards category (ESC) tables. The ESC tables contain pass, fail, and gross polluter cutpoints for HC, CO, and NO for ASM and TSI emissions tests. There are 33 ASM ESCs and 23 TSI ESCs for each vehicle age-type-weight group in the California vehicle fleet. Sample ASM and TSI cutpoint equations are shown below for an ESC "Type 1" vehicle, which is a 1966-1967 model year car or truck weighing less than 6,000 lbs [10, 11]:

$$HC_{ASM\ 5015} = 435.4 + 436{,}041.7/VTW\ [ppm] \qquad HC_{TSI\ 2500} = 850\ [ppm]$$
$$CO_{ASM\ 5015} = 4.26 + 4{,}453.19/VTW\ [\%] \qquad CO_{TSI\ 2500} = 7.0\ [\%]$$
$$NO_{ASM\ 5015} = 2{,}659.3 + 170{,}3703.7/VTW\ [ppm] \qquad NO_{TSI\ 2500} = N/A$$

$$HC_{ASM\ 2525} = 385.4 + 436041.7/VTW\ [ppm] \qquad HC_{TSI\ Idle} = 950\ [ppm]$$
$$CO_{ASM\ 2525} = 4.06 + 4453.19/VTW\ [\%] \qquad CO_{TSI\ Idle} = 8.0\ [\%]$$
$$NO_{ASM\ 2525} = 2459.3 + 170373.7/VTW\ [ppm] \qquad NO_{TSI\ Idle} = N/A$$

It should be pointed out that ASM cutpoints are a linear function of the vehicle test weight (VTW) as measured during the emissions test, while TSI cutpoints are constant. Only a fraction of vehicles (128,382 vehicles or 15.3%) are subject to the TSI test while the majority of vehicles (709,069 or 84.7%) are

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subject to the ASM test. Note also that ASM tests measure HC, CO, and NO emissions, in parts per million (ppm), percent, and ppm, respectively, while TSI tests only measure HC and CO emissions.

From Table 1, we can see that the ASM5015 test and the ASM2525 test yield very similar results. It is also clear that the percentage of vehicles that simultaneously violate both HC and CO (~2.5%) is not far from the percentage that violate for HC (~3.0%) or CO (~4.0%) alone. These finding may suggest that vehicles that exceed cutpoints for either HC or CO are also likely to violate for both; both pollutants are related to incomplete engine combustion. This finding also implies that there may be little additional benefit (in terms of identifying gross polluting vehicles) from individually distinguishing between these two pollutants. That is, it may be possible to save resources by possibly eliminating one of the two ASM tests (e.g., ASM2525), as well as possibly one of the test pollutants (e.g., HC).

Table 1: Number of gross polluting vehicles identified by each emissions test based on existing cutpoints.

Pollutant(s)	ASM		TSI	
	5015	2525	2500	Idle
HC Only	20,696 (2.9%)	22,601 (3.2%)	1,518 (1.2%)	3,449 (2.7%)
CO Only	29,985 (4.2%)	29,029 (4.1%)	1,530 (1.2%)	2,092 (1.6%)
NO Only	26,307 (3.7%)	23,301 (3.3%)	N/A	N/A
Both: HC & CO	17,256 (2.4%)	19,182 (2.7%)	708 (0.6%)	1,281 (1.0%)
Both: HC & NO	13,115 (1.9%)	13,077 (1.8%)	N/A	N/A
Both: CO & NO	12,582 (1.8%)	12,608 (1.8%)	N/A	N/A
All: HC, CO & NO	12,532 (1.8%)	12,545 (1.7%)	N/A	N/A

N/A = Not Applicable.

While Table 1 indicates that the *same number* of vehicles are being captured by the two ASM tests, confirmation that the *same* gross polluting vehicles are being captured by the two ASM tests is made in Table 2, where only a small fraction of vehicles (less than one percent of the total) fail one test without failing both – regardless of criteria pollutant. Between 75% and 100% of the gross polluting vehicles are simultaneously captured both tests, depending on the criteria pollutant. These findings would suggest that both ASM tests are not necessary.

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Table 2: Comparison of gross polluting vehicles identified by asm tests based on existing cutpoints.

Pollutant(s)	Non-Gross Polluting Vehicles	Gross Polluting Vehicles			Total
		ASM 5015 Only	ASM 2525 Only	Both ASM Tests	
HC Only	684,403 (96.5%)	2,065 (0.3%)	3,970 (0.6%)	18,631 (2.6%)	709,069 (100.0%)
CO Only	676,249 (95.4%)	3,791 (0.5%)	2,835 (0.4%)	26,194 (3.7%)	709,069 (100.0%)
NO Only	680,577 (96.0%)	5,191 (0.7%)	2,185 (0.3%)	21,116 (3.0%)	709,069 (100.0%)
Both: HC & CO	688,939 (97.2%)	948 (0.1%)	2,874 (0.4%)	16,308 (2.3%)	709,069 (100.0%)
Both: HC & NO	695,669 (98.1%)	323 (0.0%)	285 (0.0%)	12,792 (1.8%)	709,069 (100.0%)
Both: CO & NO	696,420 (98.2%)	41 (0.0%)	67 (0.0%)	12,541 (1.8%)	709,069 (100.0%)
All: HC, CO, & NO	696,505 (98.2%)	19 (0.0%)	32 (0.0%)	12,513 (1.8%)	709,069 (100.0%)

If we perform the same analysis on the TSI emissions tests, we observe similar but not identical results. Because only a fraction of vehicles take the TSI test (i.e., vehicles are required to take the ASM test but are allowed to take the TSI test if they are too heavy or do not fit on the test dynamometer), the results in Table 1 indicate that the TSI tests capture only a small fraction and a small number of gross polluters in comparison to the ASM tests. This suggests that it might be possible to either eliminate the TSI test altogether or tighten its cutpoints (which are different than the ASM cutpoints) to improve effectiveness. Unlike the two ASM tests, a comparison of the vehicles captured by the two TSI tests indicates that the TSI Idle test may be more effective than the TSI 2500 test, as shown in Table 3. While the number of vehicles captured either both test is small, they do not seem to be capturing the *same* gross polluting vehicles.

Table 3: Comparison of gross polluting vehicles identified by tsi tests based on existing cutpoints.

Pollutant(s)	Non-Gross Polluting Vehicles	Gross Polluting Vehicles			Total
		TSI 2500 Only	TSI Idle Only	Both TSI Tests	
HC Only	124,492 (97.0%)	441 (0.3%)	2,372 (1.8%)	1,077 (0.8%)	128,382 (100.0%)
CO Only	125,703 (97.9%)	587 (0.5%)	1,149 (0.9%)	943 (0.7%)	128,382 (100.0%)
Both: HC & CO	126,926 (98.9%)	175 (0.1%)	748 (0.6%)	533 (0.4%)	128,382 (100.0%)

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Table 4 shows the amount of emissions for each pollutant captured from the different ASM and TSI tests. These tables indicate that "gross polluters" do, in fact, account for roughly one-quarter to one-half of the total CO emissions regardless of the test with 41%, 47%, 26%, and 35% of CO accounted in the ASM5015, ASM2525, TSI2500, and TSI Idle tests, respectively.

This analysis also indicates that emissions by gross polluting vehicles are not equally distributed among criteria pollutants and that more emphasis appears to have been placed on CO emissions than on HC or NO emissions (even though the definition of "gross polluter" does not indicate that CO is the primary pollutant of interest). Table 4 indicates that HC gross polluters account for roughly one-sixth to one-third of the total HC emissions with 13%, 18%, 32%, and 39% of HC emissions accounted in the ASM5015, ASM2525, TSI2500, and TSI-Idle tests, respectively. At the same time, the ASM tests (for which NOx is available) indicate that vehicles identified as gross polluters only account for about 13% of overall NOx emissions. In the following section, we explore how the subset of gross polluting vehicles change if emissions are equally distributed among criteria pollutants – not focused on CO, as shown above.

Table 4: Amount of emissions measured from gross polluting vehicles based on existing cutpoints.

Pollutant	ASM		TSI	
	5015	2525	2500	Idle
HC (ppm)	5,876,947 (12.8%)	5,567,519 (17.9%)	1,356,161 (32.0%)	2,940,378 (39.2%)
CO (%)	89,284 (40.7%)	84,422 (46.5%)	7,230 (26.4%)	10,810 (35.1%)
NO (ppm)	37,356,119 (12.9%)	27,395,369 (12.7%)	N/A	N/A

N/A = Not Applicable.

In this section, we explore how both the subpopulations of gross polluting vehicles and the proportion of pollutants captured change if the gross polluter cutpoints are redefined. We use two simple but very different cutpoint scenarios, each of which would have different implications on the resulting gross polluter populations. Because the TSI tests account for such a small fraction of gross polluting vehicles and because NOx is neglected, all of the exploratory analysis presented here focuses on the two ASM tests.

The 10% increase scenario

In this scenario, cutpoints were redefined as being 10% higher than the existing allowable gross polluter emissions cutpoints. In theory, this incremental change should reduce the overall gross polluter population by reclassifying "borderline" gross polluters as non-gross polluters, but it is not obvious which subsets of gross polluting vehicles will be identified under this scenario.

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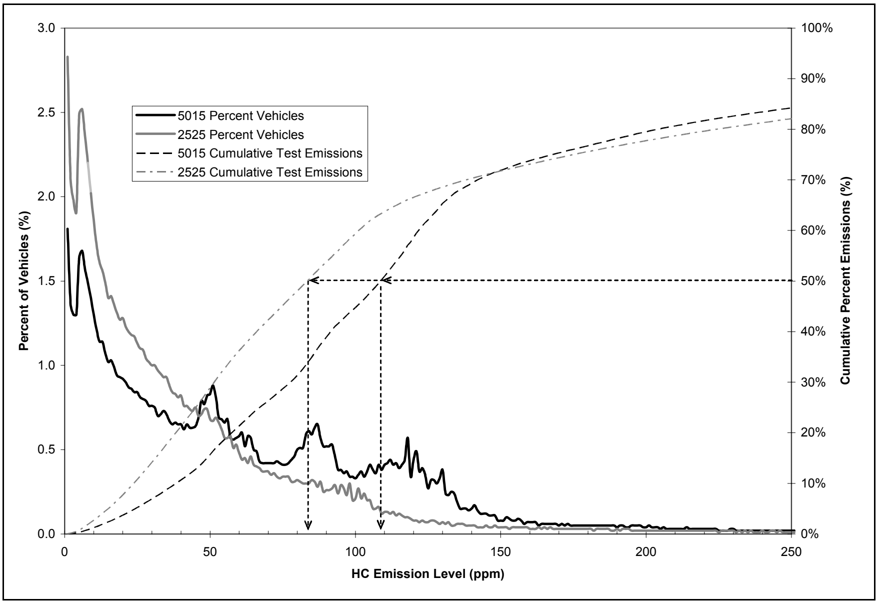

Figure 1: Identification of HC gross polluter cutpoints (ASM Tests Only).

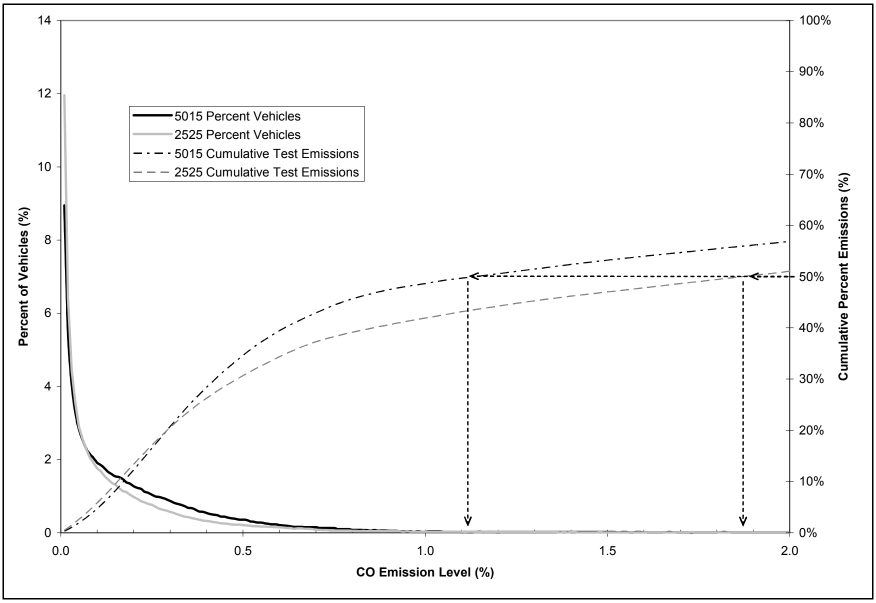

Figure 2: Identification of CO gross polluter cutpoints (ASM Tests Only).

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The "Equitable Pollutant" (EP) scenario

In this scenario, cutpoints were redefined to capture half of the total emissions produced by all vehicles *for each criteria pollutant* – regardless of vehicle age, type, weight, or emissions control technology. In theory, this change would result in an increase in the number of gross polluting vehicles by placing equal weight on the three criteria pollutants and identifying the worst polluting vehicles of each pollutant as gross polluters.

This scenario involves identifying cutpoints which correspond to the levels at which 50% of the total emissions lie for each criteria pollutant and can be accomplished by plotting cumulative distribution functions (CDF) for each pollutant and each emissions test. The CDF of emissions for HC is shown in Figure 1. The observed frequency of vehicles (indicated on the left vertical axis) which exhibit the emission levels presented on the horizontal axis are shown, while the secondary vertical axis indicates how the monotonically increasing CDF of emissions increase from 0 toward 100% as emission levels rise. The cutpoints of approximately 109 ppm and 83 ppm can be interpreted from Figure 1 based on the ASM5015 and ASM2525 tests, respectively. Additional analysis indicates 122,976 vehicles, or roughly 17% of the fleet, account for half of all the HC emissions according to the ASM5015 test, while over 92,000 vehicles, or 13% of the fleet, account for half of all HC emissions according to the ASM2525 test.

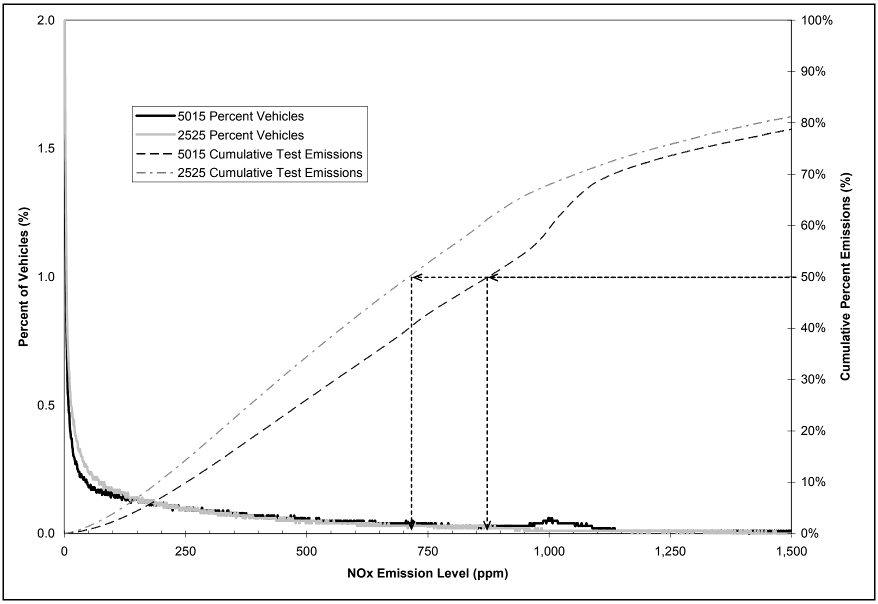

Figure 3: Identification of NOx gross polluter cutpoints (ASM Tests Only).

The CDF of emissions for CO is shown in Figure 2 along with the identified cutpoints of approximately 1.14% and 1.87%, based on the ASM5015 and ASM2525 tests, respectively. These cutpoints would categorize almost 30,000

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vehicles, 4.2% of the fleet, and 19,400 vehicles, or 2.7% of the fleet, as gross polluting vehicles for CO. The CDF for NOx, shown in Figure 3, illustrates the cutpoints of approximately 874 ppm and 771 ppm, based on the ASM5015 and ASM2525 tests, respectively.

Table 5. Summary of identified gross polluter cutpoints (ASM Tests Only).

Scenario	ASM 5015			ASM 2525		
	HC (ppm)	CO (%)	NOx (ppm)	HC (ppm)	CO (%)	NOx (ppm)
Existing*	304	2.12%	1,991	252	2.21%	1,823
10% Increase* [% Change]	334 [+9.9%]	2.33% [+9.9%]	2,189 [+9.9%]	277 [+9.9%]	2.43% [+10.0%]	2,005 [+10.0%]
"Equitable Pollutant" [% Change]	109 [-64.1%]	1.14% [-46.2%]	874 [-56.1%]	83 [-67.1%]	1.87% [-15.4%]	711 [-61.0%]

* - Weighted average.

In Table 5, the identified cutpoints are summarized. For the existing cutpoints and the 10% increase scenario, the cutpoint is a weighted average (over all ESCs), based on the observed frequency of vehicles at the different emission levels. For the equitable pollutant scenario, the cutpoints are fixed among pollutants, regardless of ESC. Also shown in the table is the change induced by each scenario relative to the existing cutpoints. The corresponding gross polluting vehicles and their emissions identified by each set of cutpoints are shown in, in Table 6 and Table 7, respectively. These two tables also show the change relative to the existing cutpoints. These tables can be used together to understand how changes in the gross polluter population result in changes to gross polluting vehicles or their emissions.

Table 6: Summary of gross polluting vehicles (ASM Tests Only).

Scenario	ASM 5015			ASM 2525		
	HC (ppm)	CO (%)	NOx (ppm)	HC (ppm)	CO (%)	NOx (ppm)
Existing (%)	20,696 (2.9%)	29,985 (4.2%)	26,307 (3.7%)	22,601 (3.2%)	29,029 (4.1%)	23,301 (3.3%)
10% Increase (%) [% Change]	18,940 (2.7%) [-8.5%]	28,547 (4.0%) [-4.8%]	23,116 (3.3%) [-12.1%]	20,704 (2.9%) [-8.4%]	27,676 (3.9%) [-4.7%]	20,816 (2.9%) [-10.7%]
"EP" (%) [% Change]	122,976 (17.3%) [+494.2%]	29,628 (4.2%) [-1.2%]	105,229 (14.8%) [+300.0%]	92,262 (13.0%) [+308.2%]	19,400 (2.7%) [-33.2%]	88,665 (12.5%) [+280.5%]

These results seem to indicate that relatively small or incremental changes in gross emitter cutpoints (e.g. 10%) do not produce linear changes in emissions (as might be expected from Figures 1 through 3). Moreover, the effects of the cutpoints are not equally distributed across pollutants. For example, a 10% increase in existing gross polluter cutpoints resulted in only a 4.0% decrease in CO emissions, but also resulted in an 18.1% decrease in NOx emissions, as measured by ASM5015.

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These results suggest that efficiencies in gross polluter identification can be gained from targeting gross polluting vehicles of all three criteria pollutants, not just CO. For example, by focusing on the worst offending polluters regardless of vehicle age-type-weight group, fewer vehicles can be labelled as gross polluters of CO while significant improvements in emissions reductions can be realized. At the same time, these results also suggest that focusing on half of all pollutants produced is not the most efficient cutpoint criteria. For example, to capture half of the HC emissions exhibited in the 5015 ASM tests, the number of the worst polluting vehicles must increase from 20,696 (2.9% of the fleet) to 122,976 (17.3% of the fleet), representing nearly a five-fold increase, but the result is less than a three-fold return in emissions reductions.

Table 7: Summary of gross polluting vehicle emissions (ASM Tests Only).

Cutpoint Scenario	ASM 5015			ASM 2525		
	HC (ppm)	CO (%)	NOx (ppm)	HC (ppm)	CO (%)	NOx (ppm)
Existing (%)	5,876,947 (12.8%)	89,284 (40.7%)	37,356,119 (12.9%)	5,567,519 (17.9%)	84,422 (46.5%)	27,395,369 (12.7%)
10% Increase (%) [% Change]	5,334,124 (11.6%) [-9.2%]	85,741 (39.1%) [-4.0%]	30,610,908 (10.6%) [-18.1%]	5,079,512 (16.3%) [-8.8%]	81,178 (44.7%) [-3.8%]	22,575,334 (10.4%) [-17.6%]
"EP" (%) [% Change]	22,873,678 (49.8%) [+289.2%]	109,594 (50.0%) [+22.7%]	144,967,730 (50.0%) [+288.1%]	15,658,316 (50.3%) [+181.2%]	90,759 (50.0%) [+7.5%]	108,097,806 (50.0%) [+294.6%]

5 Conclusions and implications

The conclusions and implications of this research are the following:

- It may not be necessary to conduct both 5015 and 2525 ASM tests, because they capture roughly the same gross polluting vehicles.
- It may not be necessary to conduct ASM tests for both HC and CO, because an identified gross polluter for one pollutant is usually also identified as gross polluter for the other.
- Not all pollutants are given the same level of importance in existing gross polluter cutpoints, as greater emphasis appears to have been placed on capturing half of the CO emitted from vehicles – not half of emissions from each criteria pollutant.
- If small incremental changes to the cutpoints are made, the resulting change in emissions may not be linear nor have equal impact on gross polluters of different pollutants.
- Targeting half of the emissions produced for each pollutant is not efficient and is not the optimum cutpoint criterion.

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