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Determination of Methane Offsets as a Function of Mileage for Light-Duty Cars and Trucks

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- Draft -

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1.0 Introduction

Previous reports document how the MOBILE6 emission factor model will allocate vehicle exhaust emissions between engine start (start emissions) and travel (running emissions)[1,2]. This split allows the separate characterization of start and running emissions for correction factors such as fuel effects and ambient temperature. It also enables a more precise weighting of these two aspects of exhaust emissions for particular situations such as morning commute, parking lot and freeway driving.

Because methane does not contribute significantly to ozone formation, MOBILE attempts to separate it from total hydrocarbons in estimating vehicle emissions. This document describes methodologies for calculating this methane "offset" based on the separation of start and running emissions proposed for MOBILE6. The procedure follows the scheme of modeling the in-use deterioration of emissions as a function of accumulated mileage. For model year 1981-1993 light-duty cars and trucks, stratified into carbureted versus fuel-injected, the method parallels that used for total hydrocarbons, carbon monoxide and oxides of nitrogen. This analysis utilizes actual methane data from emissions tests conducted on vehicles from those model years.

For pre-1981 model years, data of the type used in the newer vehicles is not available. Therefore, procedures are described for estimating methane as a function of

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[1]Carey, P., P. Enns, E. Glover, and M. Sklar, "Determination of Running Emissions as a Function of Mileage for 1981-1993 Model Year Light-Duty Cars and Trucks," Report Number M6.EXH.001, October 1998.

[2]Carey, P. and E. Glover, "Determination of Start Emissions as a Function of Mileage and Soak Time for 1981-1993 Model Year Light-Duty Vehicles," Report No. M6.STE.003, October 1998.

mileage using existing data in combination with methods that are applied in MOBILE version 5.

2.0 Data

The data underlying the analysis of 1981-93 light-duty vehicles are drawn from a subset of the Federal Test Procedure (FTP) tests described in the reports cited above. These tests were conducted by EPA, the American Automobile Manufacturers Association (AAMA), and the American Petroleum Institute (API). Most, but not all, of these tests produced measurements of methane. In particular, the sample sizes from the full data set and the reduced sets for which methane is recorded are compared in the table below, subdivided by vehicle type and the model year/technology groups used to determine basic emission rates of total HC, CO and NOx.

CARS

	DATA SET	
	REDUCED	FULL
	N	N
GROUP		
81-82 CARB	580	1166
81-82 FI	88	126
83-85 CARB	203	253
83-87 FI	688	726
86-93 CARB	93	96
88-93 PFI	1361	1605
88-93 TBI	437	444

TRUCKS

	DATA SET	
	REDUCED	FULL
	N	N
GROUP		
81-83 CARB	72	180
81-87 FI	92	94
84-93 CARB	125	134
88-93 PFI	199	330
88-93 TBI	458	467

Another key data set is that based on a sample of FTP tests to which were appended a 505-second cycle without an engine start. This cycle is identical to that of Bags 1 and 3, but contains no emissions associated with the cold start of Bag 1 or warm start of Bag 3. It is referred to as the Hot Running 505 (HR505). Pure cold and warm start emissions are estimated by deducting HR505 emissions from the 505 bags that include a start.[3]

The data from this test program were used to estimate the relation between the

[3]Brzezinski, D. and P. Enns, "The Determination of Hot Running Emissions from FTP Bag Emissions", Report No. M6.STE.002, December, 1997.

HR505 and Bags 1 to 3 of an FTP. From this function, the portions of FTP emissions attributed to start and running are computed. This calculation then was applied to the large FTP data set described above for which Bags 1 to 3, but not the HR505, are measured.

3.0 Modeling Methane Deterioration in MOBILE6 - 1981-93 Vehicles

To understand the current analysis, it is helpful to review how emissions deterioration is modeled in MOBILE6. The basic method involves separating start and running emissions.

3.1 Running Emissions

For the running component, simple linear functions of emissions versus mileage are fitted by the method of least squares regression. To improve the fit at low mileage, the mean of emissions is used. This produced piecewise continuous functions in which emission rates (in grams per mile) are constant at low mileage and increase when mileage accumulation exceeds approximately 20,000 miles. The higher mileage portion of the function has constant slope in most cases, but under certain conditions the slope may change, adding a second "corner" point to the graph of emissions as a function of mileage. There was a concern that the FTP data suffer from sample bias due to the self-selecting nature of the data collection. In order to account for such bias, adjustments were made to these running emission lines using data from a large sample of inspection and maintenance tests conducted in Dayton, Ohio. (See document (1) for details.) However, methane was not recorded in these tests, so it was not possible to compute this adjustment for the analysis described in this report. Instead, we propose using a proportional adjustment for sample bias corresponding to that used for total HC.

Table 1 reports the deterioration coefficients derived for methane using the reduced data set. The first slope is always zero, reflecting the use of the low mileage mean (ZML Emissions). The first corner occurs at the mileage where the emission rate begins to slope positively. For total HC, only the 1983-87 fuel-injected car category has a second corner. With methane, several categories have two corners, while the 1983-85 carbureted car group has zero deterioration at all mileages.

The high emitter adjustment was determined as proportionately the same at a given mileage as for total HC. These adjustment factors are applied additively to the initial THC emissions. They raise or lower THC by an amount that is a linear function of mileage and is zero at mileage zero. In order to apply this factor to methane it is necessary to first compute unadjusted and adjusted THC at a given mileage. Their ratio is then multiplied by unadjusted methane to obtain adjusted methane.

Figure 1 illustrates the unadjusted and adjusted methane deterioration lines for the case of 1988 to 1993 model year port fuel-injected cars. As described, the adjustment in methane is proportional to the corresponding HC adjustment, which also is illustrated. Figure 2 shows the final adjusted methane lines by model year-technology group for cars and trucks.

3.2 Start Emissions

Deterioration of start emissions (measured in grams) was modeled somewhat differently. First, the tested vehicles were stratified into categories of "normal" and "high" emitters depending on how their FTP values compare to applicable standards. For HC and CO, the normal emitter emissions were regressed against mileage, while high emitter emissions were fitted by the mean. At a given mileage, the normal and high emitter estimates were combined in a weighted average, where the weight reflects the proportion of high emitters at that mileage. Reference (2) gives a complete description of this procedure.

Table 2 presents coefficients used to compute the start portion of emission rates at a given mileage. The majority of the groups actually show negative slope estimates for the normal emitter regression lines. However, in all but one of these, the slope is not statistically significant when tested against zero. Since negative deterioration is intuitively unexpected, it was decided to use the normal emitter mean value when the regression estimate is negative. It also is possible for estimated cold start emissions to be negative. This occurs when the fitted Hot Running 505 value exceeds the observed Bag 1 value. In the case of 1988-93 TBI cars, this produced an anomaly in which the mean methane of the high emitters is negative and the start emission deterioration line has negative slope. For this case, the deterioration line was assigned a constant value equal to its zero mile level.

Table 3 gives the fraction of high emitters estimated for THC which is used to compute the weighted average described above. These are the same values used for the full sample total HC calculations. Graphs of start emissions versus mileage for cars and trucks appear in Figure 3.

3.3 FTP Emissions

Final FTP deterioration functions are obtained by combining the start and running estimates according to their relative importance in that test. The weights used coincide with those used for HC, CO and NOx. They form the equation

$$FTP=(7.5*Run + .43*CS + .57*HS)/7.5$$

where Run is emissions in grams per mile from the running LA4 portion; CS is emissions in grams from cold start; and HS is hot start, computed as simply 0.16*CS. The factor 7.5 is the driving mileage corresponding to Bags 1 and 2 (the LA4 cycle) in the FTP.

4.0 Other Model Years

4.1 Pre-1981 Model Years

In MOBILE5, start and running emissions are not separated. MOBILE5 contains deterioration functions for methane for each of the three FTP bags. This enables the calculation of bag values at selected vehicle mileages. These values can in turn be used to compute running and start emissions when combined with the regression coefficients derived from the 77-car test data. The validity of this approach rests on the assumption that start and running emissions in older vehicles occur in a manner similar to that of late model vehicles. For carbureted cars, graphs of running and start emissions are shown in Figure 4. The graphs include the proposed MOBILE6 functions for 1981-82 and for 1983-85. It is apparent that the deterioration functions for the two versions of the model are reasonably compatible. Similar graphs for fuel injected cars and for trucks yield the same impression. Therefore, in the absence of new data, EPA proposes to separate start and running methane emissions in pre-1981 light-duty vehicles and trucks using the methodology of MOBILE6 applied to the deterioration functions employed in MOBILE5.

For diesel vehicles and motorcycles, FTP bag values are not provided in MOBILE5. Thus, it is not possible to compute running and start emissions by the method outlined above. In these cases, EPA proposes to use fractions described in a separate report[4] that are applied to total hydrocarbon deterioration functions to determine methane function coefficients.

4.2 Model Years 1994 and Later

For model year 1994 and later vehicles subject to Tier I standards, MOBILE6 predicts nonmethane hydrocarbon (NMHC) emissions directly. In the case of LEVs, the model predicts nonmethane organic gas (NMOG). No adequate methane data exist for estimating methane deterioration functions for these model years. Therefore, EPA proposes developing multiplicative methane offsets from these projections in a manner consistent with the treatment of NMHC and NMOG. In general, emission rates for those pollutants are obtained using ratios of standards that apply to the newer vehicles to those of 1993 model year vehicles. For a given class of vehicles, there exists a ratio between NMHC (or NMOG) in the two model year ranges. The proposed method would apply the same ratio to compute methane for newer vehicles.

5.0 Summary

EPA proposes combining available methane data with methods employed for methane in MOBILE5 and total hydrocarbons in MOBILE6 to develop basic emission rates for methane in MOBILE6. This results in an eclectic approach that attempts to fully utilize the data while making reasonable assumptions where insufficient data exists. In general, the assumptions are consistent with methods applied to total and nonmethane HC.

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[4]Brzezinski, D. and J. Gilmore, “Basic Exhaust Emission Rates of Open Loop Vehicles for MOBILE6," Report No. M6.EXH.005, May 1999.

Table 1: Methane Running Emission Deterioration Model Coefficients for Light-Duty Vehicles

Cars

Model Year/ Technology	ZML Emission (gr/m)	First Slope (gr/m/1000m)	First Corner (1000 miles)	Second Slope (gr/m/1000m)	Second Corner (1000 miles)	Third Slope (gr/m/1000m)
88-93 PFI	0.0167	0.0000	15.47	0.0003	67.89	0.0003
88-93 TBI	0.0240	0.0000	32.18	0.0002	N/A	N/A
83-87 FI	0.0365	0.0000	14.12	0.0006	81.29	0.0004
86-93 CARB	0.0405	0.0000	15.19	0.0002	71.91	0.0001
83-85 CARB	0.0721	0.0000	N/A	N/A	N/A	N/A
81-82 FI	0.0271	0.0000	13.92	0.0005	265.40	0.0005
81-82 CARB	0.0845	0.0000	22.11	0.0005	N/A	N/A

Trucks

Model Year/ Technology	ZML Emission (gr/m)	First Slope (gr/m/1000m)	First Corner (1000 miles)	Second Slope (gr/m/1000m)	Second Corner (1000 miles)	Third Slope (gr/m/1000m)
88-93 PFI	0.0291	0.0000	19.18	0.0005	N/A	N/A
88-93 TBI	0.0253	0.0000	16.25	0.0004	54.46	0.0003
84-93 CARB	0.1118	0.0000	36.51	0.0008	N/A	N/A
81-87 FI	0.0594	0.0000	29.76	0.0006	N/A	N/A
81-83 CARB	0.1033	0.0000	12.35	0.0002	80.35	0.0001

Table 2: Methane Start Emission Deterioration Model Coefficients for Light-Duty Vehicles

Cars

GROUP	ZML (gr/m)	SLOPE (gr/m/1000m)	MEAN METHANE HIGHS (gr/m)	MEAN METHANE NORMALS (gr/m)
88-93 PFI	0.102	-0.0002	0.178	0.095
88-93 TBI	0.084	-0.0003	-0.073	0.071
86-93 CARB	0.108	-0.0001	0.242	0.105
83-87 FI	0.115	-0.0004	0.151	0.097
83-85 CARB	0.174	-0.0001	0.601	0.172
81-82 FI	0.077	0.0008	0.335	0.116
81-82 CARB	0.177	0.0007	0.551	0.211

Trucks

GROUP	ZML (gr/m)	SLOPE (gr/m/1000m)	MEAN METHANE HIGHS (gr/m)	MEAN METHANE NORMALS (gr/m)
88-93 PFI	0.151	-0.0022	.	0.050
88-93 TBI	0.148	-0.0002	.	0.140
84-93 CARB	0.302	-0.0001	0.556	0.297
81-87 FI	0.098	-0.0000	0.183	0.098
81-83 CARB	0.423	-0.0001	0.686	0.417

Table 3: Fraction of High Emitters for Light-Duty Cars

MILES (x1000)	GROUP						
	81-82 CARB	81-82 FI	83-85 CARB	83-87 FI	86-93 CARB	88-93 PFI	88-93 TBI
2.142	0.0282	0.0203	0.0232	0.0223	0.0052	0.0184	0.0239
12.823	0.0543	0.0654	0.0158	0.0157	0.0197	0.0227	0.0251
29.335	0.1580	0.1613	0.0047	0.0406	0.0526	0.0422	0.0270
50	0.2906	0.2861	0.0917	0.1003	0.1042	0.0800	0.0386
60.006	0.3560	0.3485	0.1348	0.1298	0.1296	0.0987	0.0458
74.239	0.4503	0.4393	0.1972	0.1723	0.1661	0.1260	0.0561
87.786	0.5416	0.5275	0.2578	0.2078	0.2012	0.1525	0.0661
100.01	0.6253	0.6094	0.3135	0.2346	0.2334	0.1770	0.0753
112.948	0.7152	0.6986	0.3737	0.2634	0.2678	0.2036	0.0851
124.625	0.7976	0.7812	0.4290	0.2898	0.2992	0.2280	0.0940
135.738	0.8772	0.8620	0.4826	0.3153	0.3295	0.2518	0.1026
146.315	0.9539	0.9407	0.5345	0.3400	0.3586	0.2748	0.1110
156.38	1.0000	1.0000	0.5847	0.3638	0.3866	0.2972	0.1190
165.96	1.0000	1.0000	0.6332	0.3868	0.4135	0.3189	0.1267
175.077	1.0000	1.0000	0.6801	0.4089	0.4393	0.3398	0.1341
183.753	1.0000	1.0000	0.7253	0.4303	0.4641	0.3601	0.1412
192.01	1.0000	1.0000	0.7690	0.4508	0.4879	0.3798	0.1480
199.869	1.0000	1.0000	0.8111	0.4706	0.5108	0.3988	0.1546
207.349	1.0000	1.0000	0.8516	0.4896	0.5327	0.4171	0.1609
214.466	1.0000	1.0000	0.8907	0.5079	0.5537	0.4348	0.1669
221.241	1.0000	1.0000	0.9284	0.5255	0.5738	0.4519	0.1727
227.688	1.0000	1.0000	0.9646	0.5425	0.5931	0.4683	0.1782
233.823	1.0000	1.0000	1.0000	0.5587	0.6116	0.4842	0.1836
239.663	1.0000	1.0000	1.0000	0.5743	0.6293	0.4994	0.1887
245.22	1.0000	1.0000	1.0000	0.5893	0.6462	0.5141	0.1936
250.509	1.0000	1.0000	1.0000	0.6036	0.6624	0.5283	0.1982

(Cont.)

Table 3: Fraction of High Emitters for Light-Duty Trucks

MILES (x1000)	GROUP 81-83 CARB	81-87 FI	84-93 CARB	88-93 PFI	88-93 TBI
2.142	0.0500	0.0659	0.0000	0.0301	0.0094
12.823	0.0405	0.0515	0.0000	0.0294	0.0066
29.335	0.0733	0.0283	0.0000	0.0356	0.0202
45.05	0.1181	0.0370	0.0000	0.0546	0.0381
60.006	0.1637	0.0883	0.0164	0.0734	0.0555
74.239	0.2101	0.1393	0.0697	0.0919	0.0721
87.786	0.2573	0.1900	0.1230	0.1102	0.0884
100.678	0.3052	0.2405	0.1761	0.1281	0.1043
112.948	0.3538	0.2905	0.2291	0.1458	0.1198
124.625	0.4030	0.3401	0.2819	0.1631	0.1349
135.738	0.4528	0.3891	0.3343	0.1801	0.1497
146.315	0.5032	0.4376	0.3864	0.1968	0.1641
156.38	0.5540	0.4855	0.4381	0.2131	0.1781
165.96	0.6052	0.5328	0.4892	0.2291	0.1918
175.077	0.6568	0.5793	0.5399	0.2446	0.2050
183.753	0.7087	0.6251	0.5899	0.2599	0.2178
192.01	0.7608	0.6702	0.6393	0.2747	0.2303
199.869	0.8132	0.7144	0.6881	0.2891	0.2424
207.349	0.8656	0.7578	0.7361	0.3032	0.2541
214.466	0.9181	0.8004	0.7833	0.3169	0.2655
221.241	0.9706	0.8420	0.8297	0.3302	0.2764
227.688	1.0000	0.8827	0.8753	0.3431	0.2870
233.823	1.0000	0.9225	0.9200	0.3556	0.2973
239.663	1.0000	0.9614	0.9638	0.3677	0.3072
245.22	1.0000	0.9993	1.0000	0.3795	0.3167
250.509	1.0000	1.0000	1.0000	0.3909	0.3259

Figure 1: METHANE and THC vs. MILEAGE, RUNNING LA4, PFI CARS

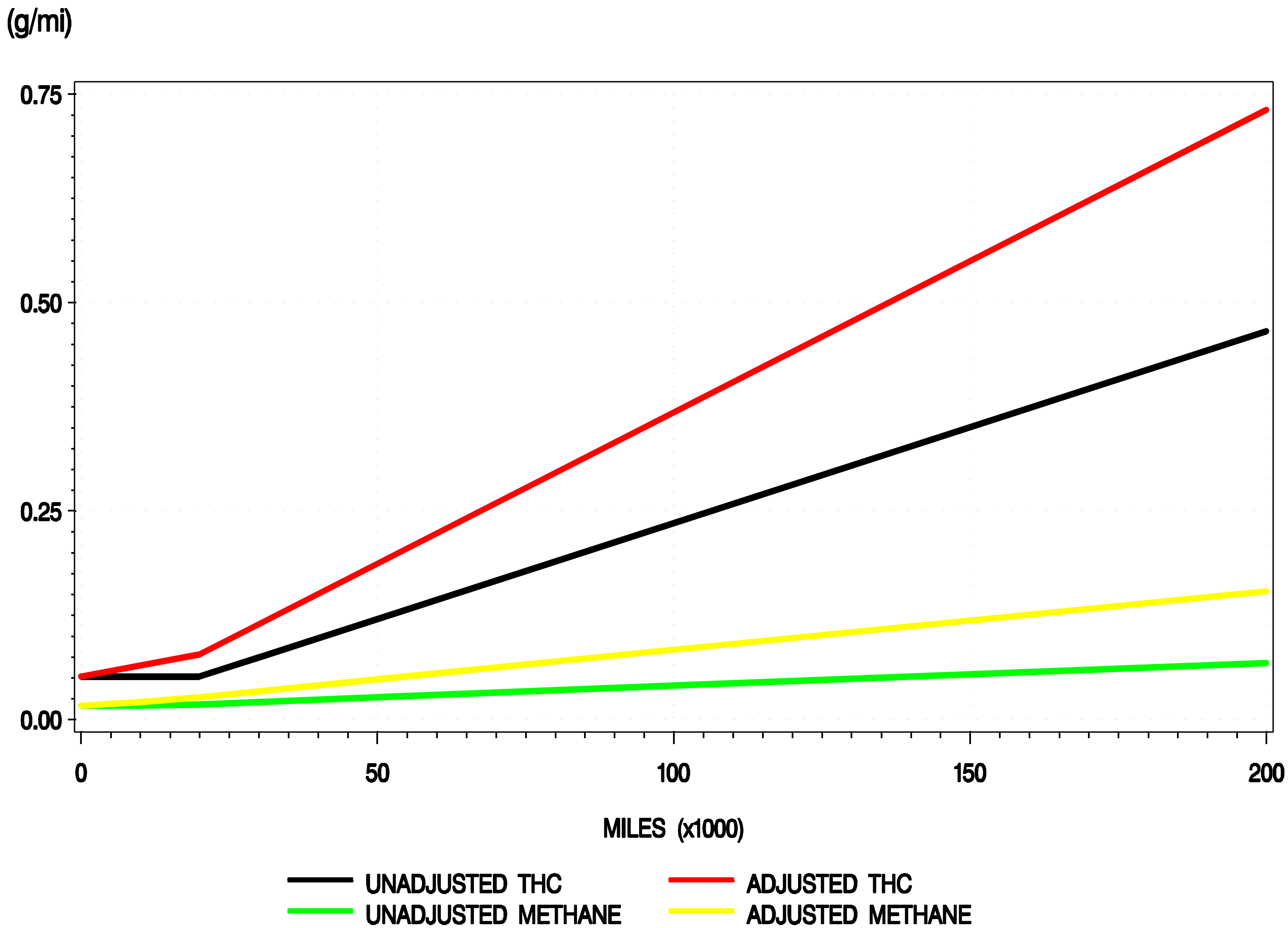
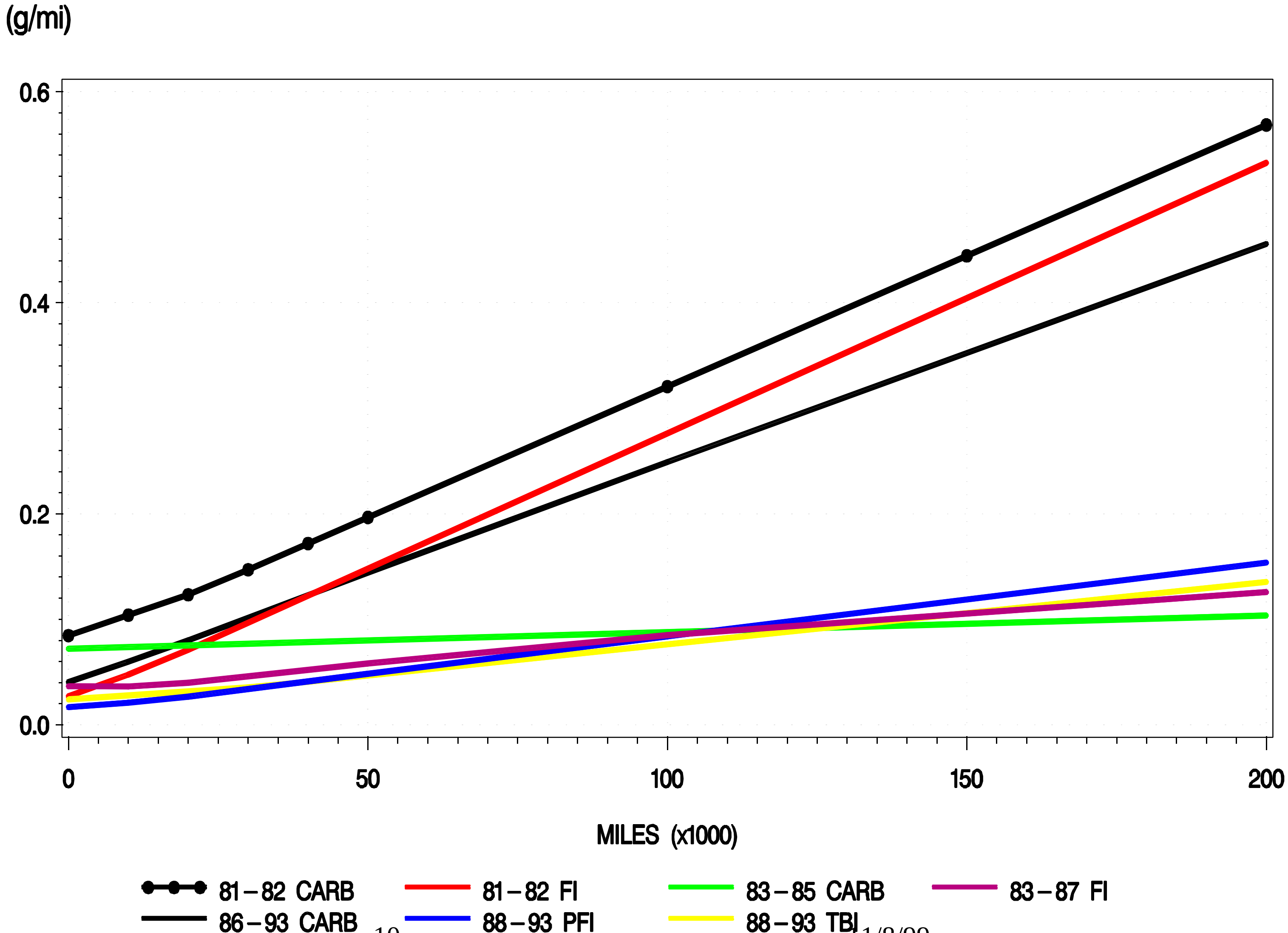


Figure 2(a): METHANE vs. MILEAGE, RUNNING LA4 CARS



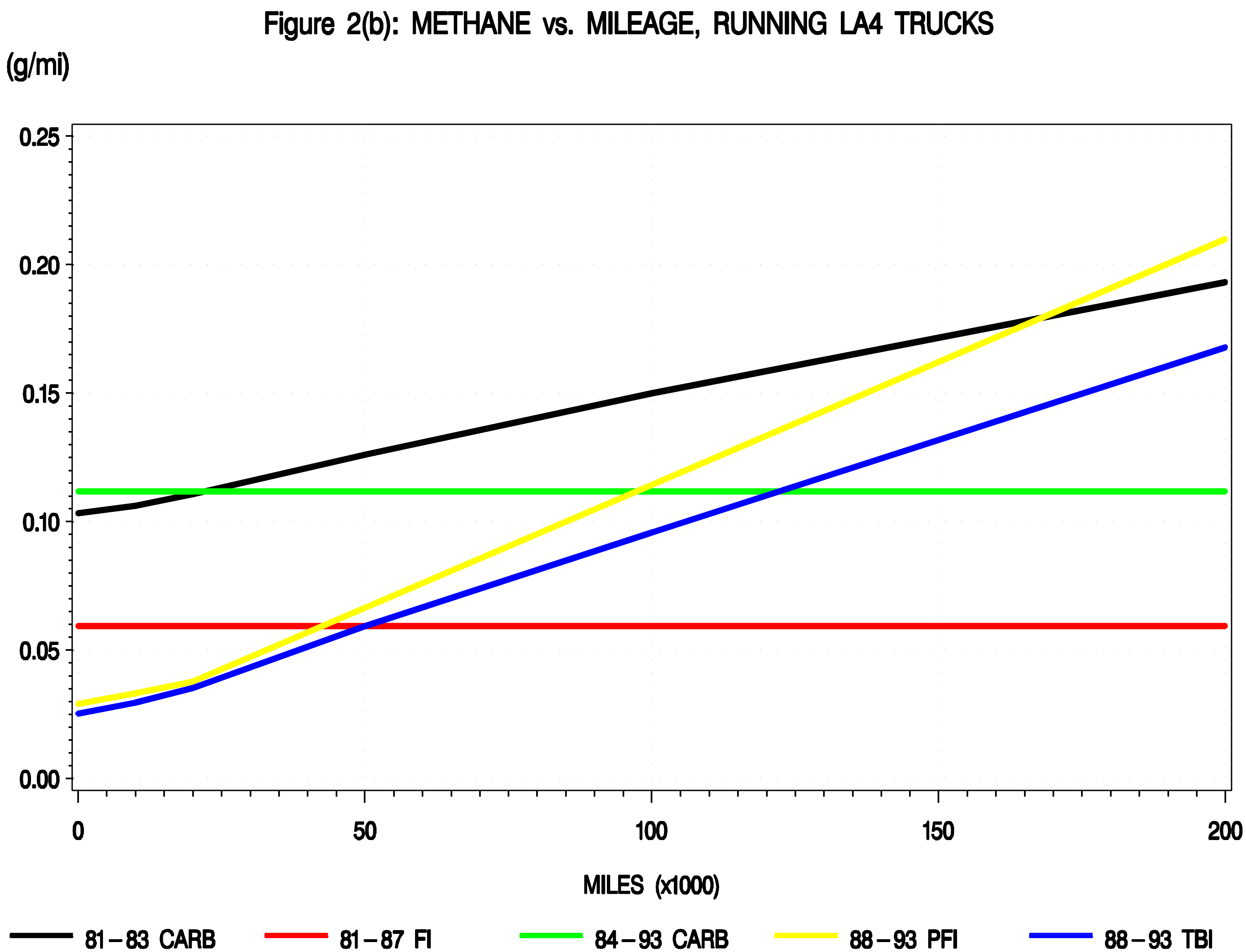


Figure 2(b): METHANE vs. MILEAGE, RUNNING LA4 TRUCKS
(g/mi)
0.25
0.20
0.15
0.10
0.05
0.00
0
50
100
150
200
MILES (x1000)
81 – 83 CARB
81 – 87 FI
84 – 93 CARB
88 – 93 PFI
88 – 93 TBI

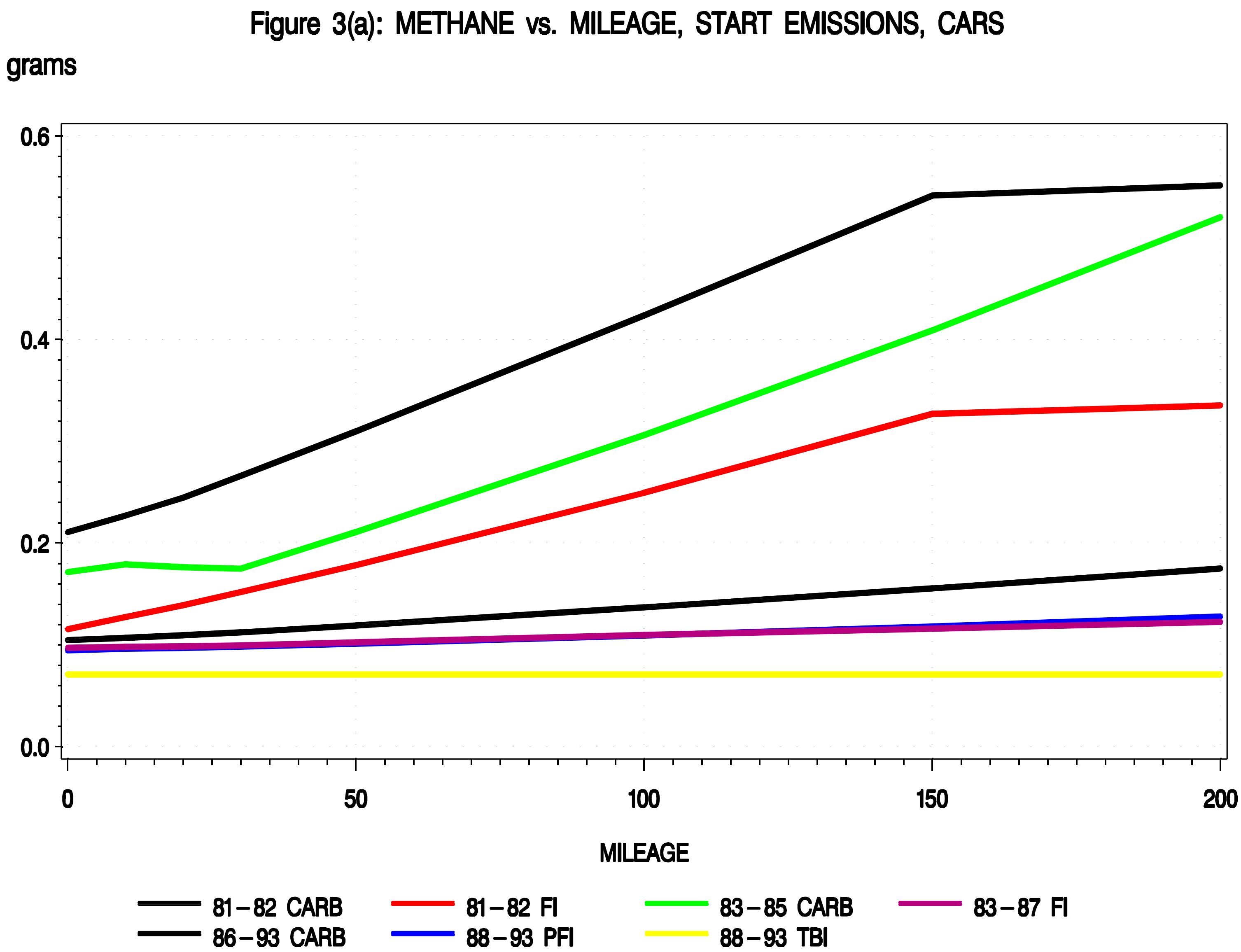


Figure 3(a): METHANE vs. MILEAGE, START EMISSIONS, CARS
grams
0.6
0.4
0.2
0.0
0
50
100
150
200
MILEAGE
81-82 CARB
81-82 FI
83-85 CARB
83-87 FI
86-93 CARB
88-93 PFI
88-93 TBI

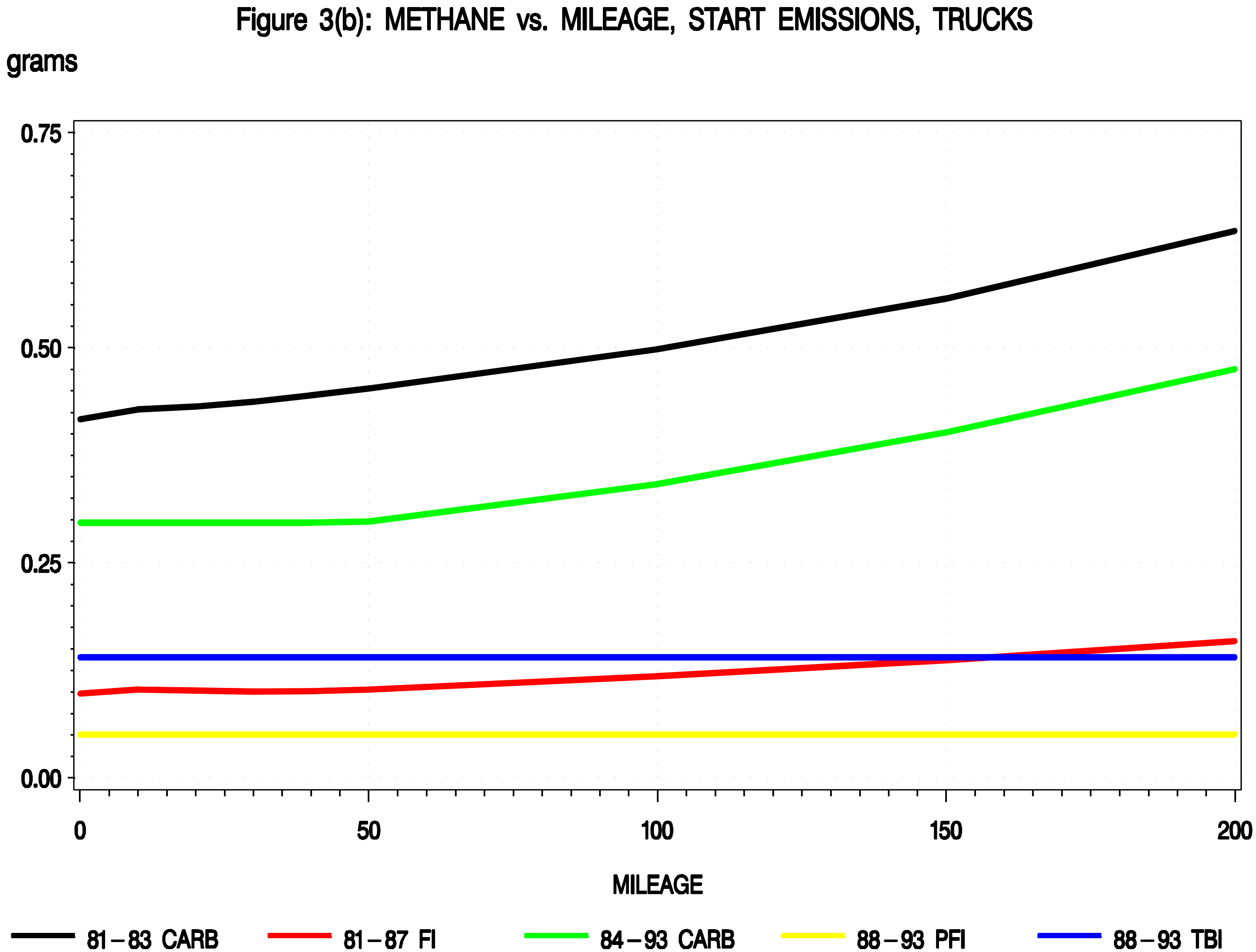


Figure 3(b): METHANE vs. MILEAGE, START EMISSIONS, TRUCKS
grams
0.75
0.50
0.25
0.00
0
50
100
150
200
MILEAGE
81-83 CARB
81-87 FI
84-93 CARB
88-93 PFI
88-93 TBI

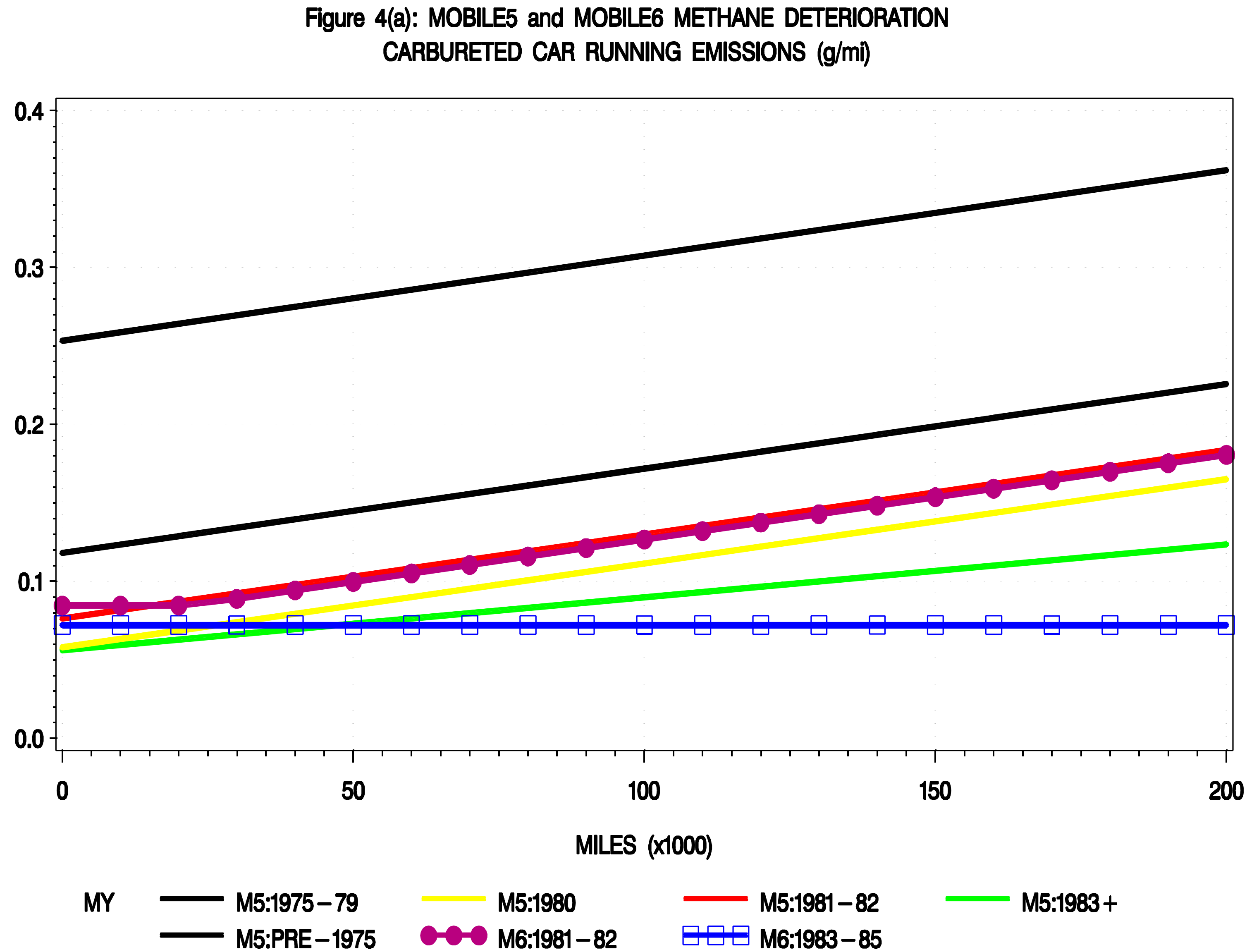


Figure 4(a): MOBILE5 and MOBILE6 METHANE DETERIORATION
CARBURETED CAR RUNNING EMISSIONS (g/mi)
0.0
0.1
0.2
0.3
0.4
0
50
100
150
200
MILES (x1000)
MY
M5:1975-79
M5:1980
M5:1981-82
M5:1983+
M5:PRE-1975
M6:1981-82
M6:1983-85

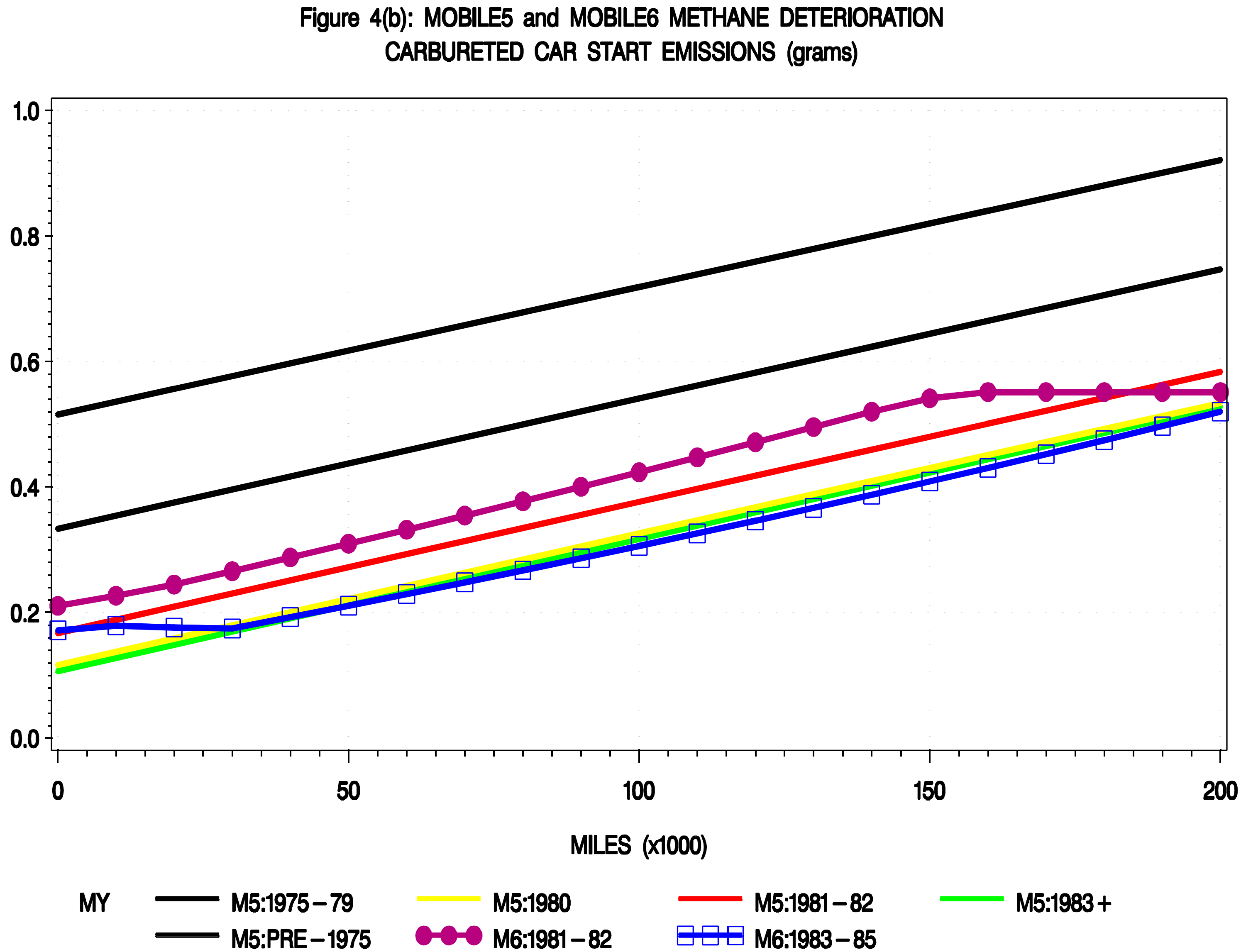


Figure 4(b): MOBILE5 and MOBILE6 METHANE DETERIORATION
CARBURETED CAR START EMISSIONS (grams)
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
MILES (x1000)
MY
M5:1975-79
M5:1980
M5:1981-82
M5:1983+
M5:PRE-1975
M6:1981-82
M6:1983-85