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Automobile Emission Trends in Canada 1960-1985

Environmental Impact and Assessment
Report EPS 8-AP-73-1

Air Pollution
Control Directorate
May 1973

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AUTOMOBILE EMISSION TRENDS IN CANADA 1960 – 1985

by

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Abatement and Compliance Branch
Air Pollution Control Directorate

Report EPS 8-AP-73-1
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ABSTRACT

The vehicle population in Canada is analyzed with respect to make-up, driving characteristics, and growth potential. The projections are then used to obtain estimates of the impact of proposed automobile emission standards on the total emissions of automobile pollutants in Canada. The influence of cold weather driving was considered in weighting the derived emission factors as well as 'on-the-road' degradation factors of emission control effectiveness. These factors were obtained from research studies carried out in Canada. The results indicate that without more stringent emission regulations the total amount of pollutants emitted by automobiles will begin to increase by the end of this decade. By using the more stringent control levels proposed, Canadian air quality will continue to improve until the later half of the next decade.

RÉSUMÉ

Les véhicules automobiles au Canada font l'objet d'études sur le plan de la composition, des caractéristiques de conduite et du potentiel de croissance. Les projections servent ensuite à obtenir des données estimatives sur les effets des normes de dégagement proposées pour les automobiles sur le total des polluants émis par celles-ci dans le pays. L'influence de la conduite par temps froid entre en ligne de compte dans l'évaluation des facteurs dérivés d'émission, tout comme l'usure, qui diminue l'efficacité de la limitation des rejets. Ces facteurs ont été déterminés à partir d'études faites au Canada. Les résultats indiquent que, sans une radicalisation des règlements sur la lutte contre les rejets, la quantité totale de polluants émis par les automobiles commencera à augmenter vers la fin de la présente décennie. Si l'on applique les normes plus rigoureuses proposées, la qualité de l'air continuera d'augmenter au Canada jusqu'à la seconde moitié de la prochaine décennie.

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1 INTRODUCTION

1.1 General

During the past decade there has been an increasing awareness of the air pollution problem created by our massive use of automobiles for personal transportation. The effects of automobile pollution were first documented in the Los Angeles basin in the early 1950's. Since then growing numbers of cities across North America and around the world have discovered that they too are polluted with the exhaust gases emitted by the automobile.

In an effort to abate this degradation of air quality, particularly in Canada's urban centers, the Federal Government passed regulations on January 1, 1971, under the Motor Vehicle Safety Act. These included legislation for the control of emissions from all new motor vehicles. The standards now in force and those proposed for 1975 and 1976 are based on U.S. legislation (Table 1) calling for a 90% overall reduction in automobile emissions between 1970 and 1976.*

The basic assumption of the Federal Government that the American standards will provide adequate safeguards for Canadian air quality, although intuitively valid, has never been documented in any comprehensive manner.

Accordingly, the purpose of this report is to establish the characteristics of the Canadian car population and develop projections to 1985. From these parameters estimates of the total automobile emissions, given various regulatory alternatives, will be developed.

1.2 Synopsis of Methodology

To ascertain the Canadian automobile pollution burden, it was first necessary to compile accurate automobile statistics. From this 'data base' it was possible to consider the influence of car 'mix', driving habits, fuel economy, and climate on automobile rates. These emission rates were then applied to the vehicle-miles estimates to obtain a total emission figure.

Many of the parameters had to be estimated from very limited data; therefore it is expected that the results will be reassessed continually in the light of new or more detailed data.

The effects of various regulatory alternatives were also investigated. The alternatives were considered to be:

(1) adoption of the 1975/76 regulations; or

(2) rejection of the 1975/76 proposed regulations, requiring only the 1973 standards.

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* Subsequent to completion of this report Canada has clarified its position regarding these standards (see Addendum).

TABLE 1 REVIEW OF PRESENT AND PROPOSED EXHAUST EMISSION STANDARDS

(Appropriate Test Methods Should be Consulted For Method of Measuring for Compliance)

		Canada				U.S.A.			
Vehicle	Pollutant	1973	1974	1975[a]	1976[a]	1973	1974	1975	1976
Light Duty Gasoline	HC (g/mile)	3.4	3.4	0.41	0.41	3.4	3.4	0.41	0.41
	NO_x (g/mile)	3.0	3.0	3.1	0.40	3.0	3.0	3.1	0.40
	CO (g/mile)	39.0	39.0	3.4	3.4	39.0	39.0	3.4	3.4
Light Duty Diesel	HC (g/mile)							0.41	0.41
	NO_x (g/mile)	Nil	Nil	Nil[b]	Nil[b]	Nil	Nil	3.1	0.40
	CO (g/mile)							3.4	3.4
Heavy Duty Gasoline	HC (ppm)	275	—[b]	—[b]	—[b]	275 }		16 g/bhph[c]	
	NO_x	Nil				Nil }			
	CO (%)	1.5				1.5		40 g/bhph[c]	
Heavy Duty Diesel	HC (ppm)		—[b]	—[b]	—[b]	275 }		16 g/bhph	
	NO_x					Nil }			
	CO (%)					1.5		40 g/bhph	
	Opacity								
	Accel (%)					40	20	20	20
	Lug (%)					20	15	15	15
	Peaks (%)						50	50	50

[a] Proposed standards.

[b] Canadian situation under review.

[c] Grams per brake horsepower per hour.

As it is not presently possible to relate the calculated emissions from automobiles to ambient air quality, this study can only indicate general trends in the contribution of automobile emissions to the air pollution problem in Canada. However, work is now underway within Environment Canada to clarify the situation.

2 CANADIAN AUTOMOBILE STATISTICS

The incomplete nature of Canadian automobile statistics necessitated partial reliance on American data for this study. Because of social and economic differences between the two countries an error is created by applying these data to Canada, the extent of which will not be known until better Canadian statistics are available. However, for the purpose of this paper the error introduced is assumed negligible.

2.1 Automobile Population

According to Statistics Canada (1) 6 602 176 automobiles were operating on Canadian roads in 1970. This number represented a 2.7% increase from the previous year and a similar increase is expected in the 1971 figures. The passenger automobile is acknowledged as the largest contributor to the environmental problems presented by motor vehicles as they comprise 77.7% of the total number of motor vehicles in Canada. The percentages of total passenger-miles travelled in Canada using automobiles were estimated to be 83.1% for intercity and 97.6% for urban travel (2). Although the other forms of motor vehicles do play an important role in air pollution, their impact is usually limited to specific nuisance or concentration effects.

2.2 Geographical Distribution

Using information obtained from Statistics Canada (1) and R.L. Polk and Co. (Canada) Ltd. (3), it was found that approximately 52% of all cars are registered in 12 Canadian cities (Figure 1). Also, recent studies undertaken by Central Mortgage and Housing Corporation (4) and Transport Canada (5) indicate that 50% of the total vehicle-miles travelled in Canada are accumulated in urban centers. Thus, at least half of the total pollution burden created by automobiles is exhausted in our major cities. The remaining emissions are widely dispersed in rural communities and on high-speed highways.

2.3 Comparison of U.S. with Canadian Urban Centers

Analyzing the Canadian automobile population requires a determination of whether Canadian cities are statistically comparable to U.S. cities. A study by Wilbur Smith and Associates (6) indicated that when one compares the population density and peak hour downtown cordon counts of North American cities, the major Canadian cities are at least as dense as

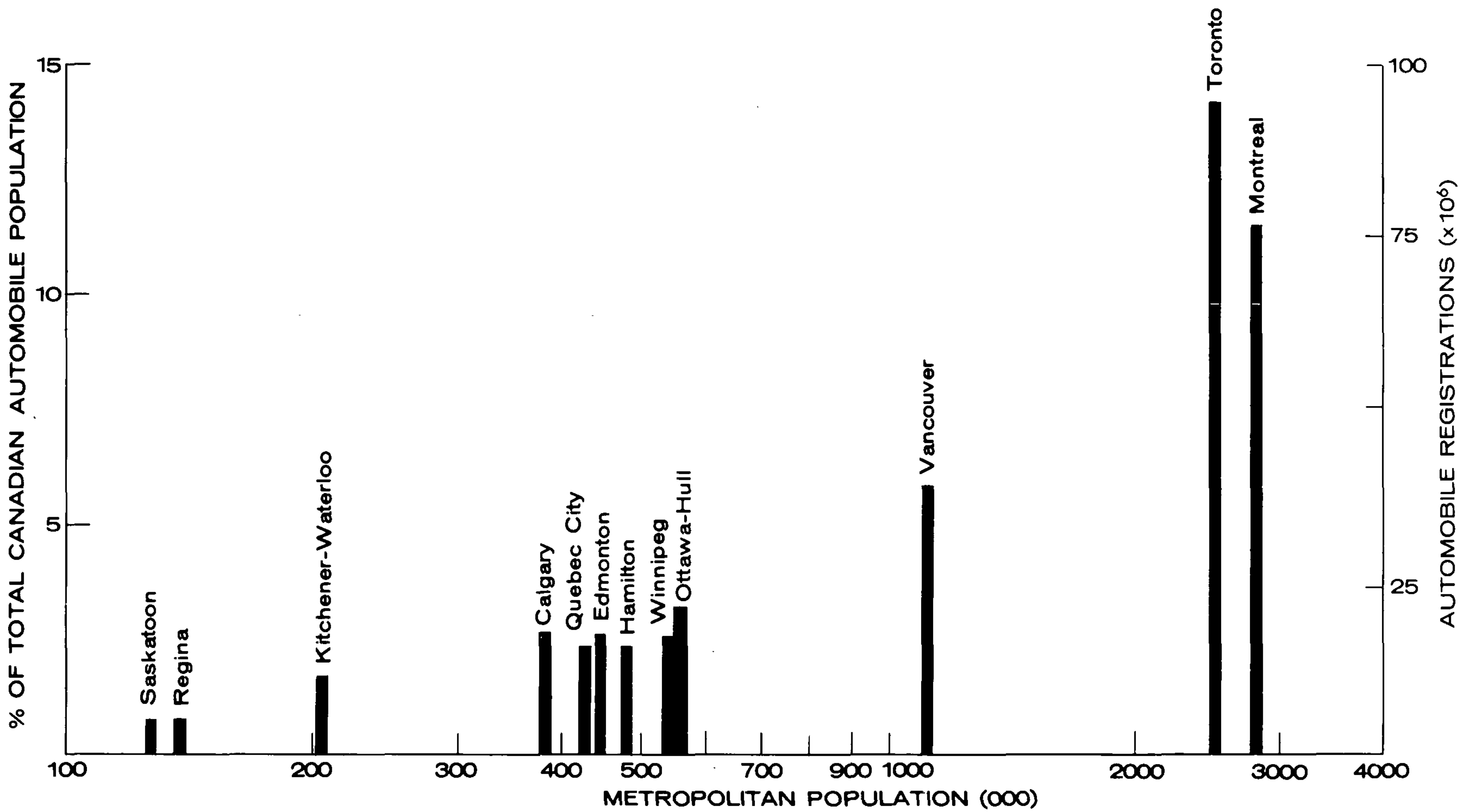

FIGURE 1 CANADIAN AUTOMOBILE DISTRIBUTION BY CITY SIZE (12 SELECTED CITIES)

their U.S. counterparts (Table 2). In fact, Montreal is surpassed only by New York City in core population density. We must therefore deduce that density of automotive emissions in Canadian cities is on a par with comparable-sized U.S. cities. Comparison of air quality observation for matched U.S. Canadian cities confirms this deduction. Thus, we contend that the contribution of the automobile to air pollution is of the same relative significance in our two countries and that a similar degree of abatement is required.

2.4 Vehicle Age and Miles Distribution

Using data from R.L. Polk and Co. (Canada) Ltd. (7) a vehicle age distribution for Canada was developed (Table 3); the average age of the cars on Canadian roads is 4.7 years. The comparable figures for the U.S. and Sweden are 5.6 (8) and 5.4 years (9), respectively.

Besides the variation in the national age characteristics a sizeable difference in vehicle age among various Canadian cities exists (Table 4). These figures imply that in our two major metropolitan areas the impact of proposed emission standards could be rapid because of the preponderance of new automobiles.

To approximate the distribution of total vehicle-miles travelled by different age groups, U.S. Department of Commerce data (Table 5) were used, as no Canadian mileage characteristics were available. The assumption here that driving and vehicle population characteristics of U.S. and Canadian vehicles are similar was made to allow inclusion of the American data in the Canadian calculations. It is possible that future data may be compiled that would allow for derivation of a vehicle-miles distribution specific to Canada.

2.5 Automobile Service Lifetime

In the U.S. and Sweden data are available that allow for the calculation of service lifetime. Similar Canadian data could only be approximated by analysis of the 1968 "Vehicles in Operation" study by R.L. Polk (Canada) Ltd. The data indicate that the average service lifetime of a Canadian car is 9.6 years; this compares with the published U.S. figure of 11 years (1968) and the Swedish figure of 11.3 (1968) (10). This shorter lifetime may partly be attributed to Canadian climatic conditions and the use of salt on highways (11).

3 FUEL ECONOMY AND VEHICLE-MILES

3.1 Estimating Fuel Economy

To calculate accurately the total vehicle-miles travelled each year in Canada, and thus the total automobile emissions, good estimates of fuel economy are imperative. Such estimates were not available from any Canadian source. However, various values for average fuel economy have been determined by several agencies.

TABLE 2 SELECTED DENSITY CHARACTERISTICS OF AMERICAN AND CANADIAN CITIES [a]

City	Urbanized Area Population	Central City Population	Density (persons/ sq. mile)	Peak-Hour Downtown Cordon Count Data, 1-Way Heavy Direction (person trips)
New York City	16 206 800	7 894 900	26 300	848 000
Chicago	6 714 600	3 367 000	15 100	223 000
Philadelphia	4 021 100	1 948 600	15 200	177 000
Boston	2 652 600	641 100	14 000	152 000
Cleveland	1 959 900	750 900	9 900	75 000
Toronto	1 881 000	665 000	20 000	76 000
Montreal	2 437 000	1 145 000	23 500	83 000
San Francisco	2 987 900	715 700	15 800	130 000
Washington	2 481 500	756 500	12 300	138 000
Atlanta	1 172 800	497 000	3 800	50 000
Dallas	1 338 700	844 400	3 200	62 000
Pittsburgh	1 846 000	520 100	9 400	56 000
Seattle	1 238 100	530 800	6 400	36 000
Vancouver	1 000 000	440 000	10 000	45 000

[a] Source: Urban Transportation Concepts, Wilbur Smith & Associates, 1970.

TABLE 3 CANADIAN VEHICLE AGE DISTRIBUTION [a]

Vehicle Age (Years) From End of Model Year (Oct. 1)	Vehicle Population As of July 1, 1968 (%)	Vehicle Population By Full Model Year (%)
0	8.6	10.5
1	11.8	11.5
2	12.4	12.1
3	11.7	11.5
4	10.8	10.6
5	8.5	8.3
6	7.4	7.2
7	5.9	5.7
8	5.3	5.2
>8	17.6	17.4

[a] Source: R. L. Polk (Canada) Co. Ltd.

TABLE 4 AVERAGE VEHICLE AGE (1968) [a]

	Years
All Canada	4.7
U.S.A.	5.6
Sweden	5.4
Toronto	3.7
Montreal	3.5
Vancouver	5.5

[a] Source: R. L. Polk (Canada) Co. Ltd.

TABLE 5 PERCENTAGE OF ANNUAL VEHICLE MILES TRAVELLED BY DIFFERENT AGE GROUPS [a]

Vehicle Age (Years)	Total Annual Vehicle Miles (%)
1	15.73
2	13.64
3	12.02
4	10.07
5	9.35
6	8.18
7	7.5
8	6.6
9	5.3
10	4.3
11	2.8
12	1.7
13	0.8
14	0.4
>14	1.6

[a] Source: U.S. Department of Commerce.

Statistics Canada has been using 13.72 miles/imp gal (mpig), a Canadian average which is based on a quick survey of a small fleet of selected automobiles. Officials of Statistics Canada admit that this figure is probably incorrect and hope to undertake a major study dealing with fuel economy and vehicle-miles in the near future.

For 1970, the U.S. Environmental Protection Agency uses the values 12.5 mpg (12) (15 mpig) as an average fuel economy for all gasoline-powered motor vehicles and 14 mpg (13) (16.8 mpig) for the average automobile. However, because of the higher percentage of small cars in Canada than in the States, the U.S. values should not be applied to Canadian calculations. Therefore Canadian fuel economy values based on the Canadian condition were newly determined.

3.2 Trends in Engine Design

Important factors in the consideration of fuel economy are engine displacement, compression ratio, and horsepower characteristics. Generally, fuel economy varies inversely with engine displacement and horsepower and directly with compression ratio. The latest known study that compiled engine parameters was a 1968 publication by Ethyl Corporation (14) in the U.S. It considered American-manufactured automobiles only and indicated a rise in brake horsepower, displacement, and compression ratio over the last decade (Figure 2). Although the general trend upward is expected to continue for brake horsepower and displacement, the compression ratio has dropped in recent years to accommodate the use of low-lead fuels and to reduce exhaust emissions. When applying these data to the Canadian case, the displacement and horsepower values are expected to be slightly lower and the compression ratio marginally higher than the Ethyl values because of our higher percentage of small cars. This influence will result in higher fuel economy for the average Canadian automobile.

3.3 Fuel Economy Data

A literature search was undertaken to obtain a factually based estimate of average fuel economy. The Canadian car population was divided into three categories: (1) imports and American subcompacts; (2) compacts, intermediates, and semi-sports; and (3) full-sized cars. Using historical sales data, percentage of market statistics were developed from 1960 to the present (Figure 3) (4). A major increase in the sales of compact and subcompact cars has occured in this past decade. This trend is expected to continue until small (i.e. compact and subcompact) cars comprise approximately 50% of the new car market.

Fuel economy characteristics of various cars in the years 1960-1972 were compiled from automotive magazines such as "Car and Driver", "Track and Traffic", "Consumer Bulletin", and "Road and Track". The majority of these test's results were based on highway

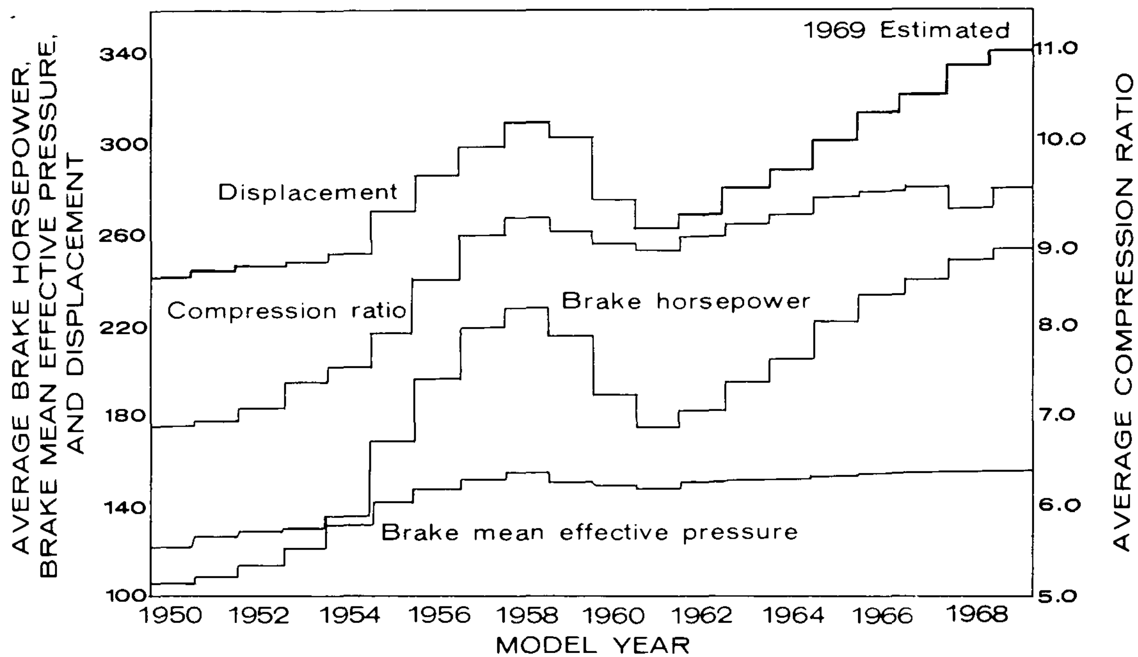

FIGURE 2 TRENDS OF AMERICAN PASSENGER CAR ENGINE DESIGN

Source : Ethyl Corp.

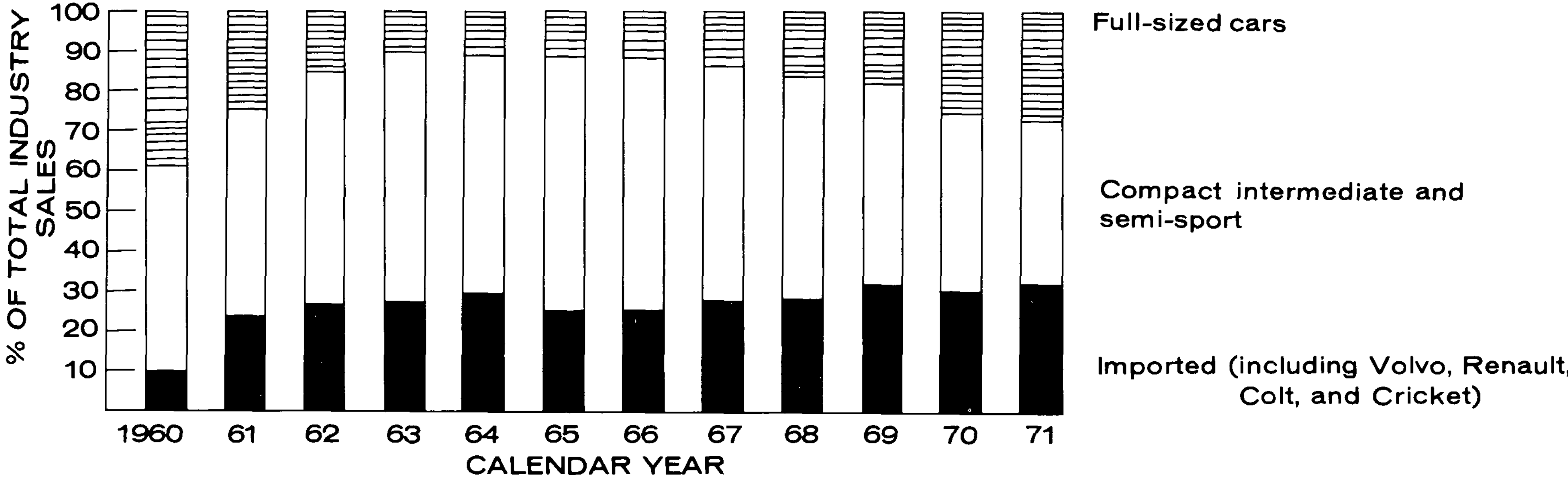

FIGURE 3 NEW CAR SALES AS PERCENTAGE OF MARKET

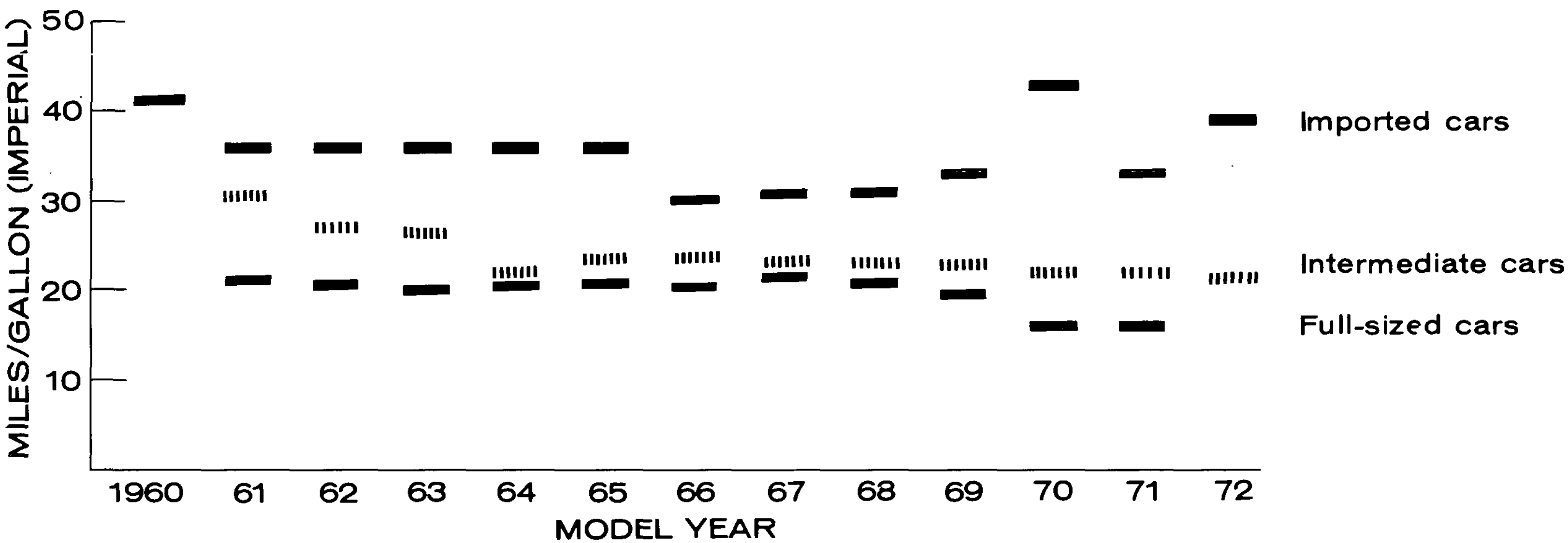

FIGURE 4 FUEL ECONOMY BY MODEL YEAR (at 50 m p h)

speeds. The various classes were averaged (Figure 4) and then the categories were weighted by their annual sales to obtain overall model-year averages (Table 6). As these numbers represent summer highway driving only, estimates were made on the effect of urban driving, poor tuning, and winter conditions on fuel economy (Table 7).

Using vehicle age distribution figures and the fuel economy values (weighted by sales and driving conditions) based on the model year, a fuel economy estimate may be developed for the total automotive population by calendar year (Table 6).

3.4 Gasoline Sales

Statistics of retail gasoline sales were obtained from Statistics Canada (15). Figure 11 illustrates the dramatic increase in fuel consumption that has paralleled our increasing vehicle population. It should be noted that only the taxable sales were consumed on public roads or highways and essentially all that gallonage was consumed by automobiles or light duty trucks.

3.5 Automobile Vehicle-Miles

Estimates of the total vehicle-miles travelled by automobiles in Canada were obtained from the gasoline sales and fuel economy figures. The results indicate that in 1970 approximately 94.2 billion vehicle-miles were accumulated by automobiles in Canada. Full tabulation of results is presented in Table 9.

4 EFFECTS OF THE CANADIAN CLIMATE ON EMISSIONS FROM AUTOMOBILES

4.1 Temperature Characteristics

An essential parameter in any discussion of automobile emissions must be ambient conditions. Obviously the climatology of even the most southern portions of Canada is substantially different from the vast majority of continental U.S. Table 8 illustrates the temperature difference between southern California and the Toronto-Montreal 'corridor'. These regions were chosen to represent the 'worst-case' air quality areas in the two countries.

4.2 Effect of Temperature on Vehicle Emissions

Although no comprehensive study has been completed investigating ambient temperature effects on engine emissions, some initial work has been done by the U.S. Bureau of Mines (16) on fuel volatilities and their influence on vehicle emissions. Much of this work was done with varying temperatures. The results indicate that HC and CO exhaust emissions increase with lower ambient temperatures (Figures 5 and 6). The evaporative emissions are reduced to insignificant levels when the ambient temperature is below the freezing point. However, the

TABLE 6 SALES STATISTICS AND GAS ECONOMY FOR MODEL YEARS 1972-1960

(Class A, imports and subcompacts; B, intermediates, compacts, and semi-sport; C, full-sized cars)

Year	Class	% of Total Sales[a]	Avg. Fuel Consumption[b] @ 50 mph (mpig)	Model Year Avg. (mpig)
1972	A		39.1[c]	
	B		21.0[d]	
	C			
1971	A	26.7	33.3[c]	
	B	30.4	21.7[d]	22.35
	C	42.9	16.0[e]	
1970	A	25.0	43.2[c]	
	B	30.0	22.9[d]	24.87
	C	45.0	16.0[e]	
1969	A	18.0	33.5[c]	
	B	30.3	23.0[d]	23.29
	C	51.7	19.9[f]	
1968	A	16.0	31.4	
	B	27.2	23.6	23.31
	C	56.8	20.9	
1967	A	13.0	31.0[e]	
	B	26.6	24.0	23.71
	C	60.4	22.0	
1966	A	11.0	30.1	
	B	24.5	23.8	22.05
	C	64.5	20.2	
1965	A	11.3	36.8	
	B	24.0	23.5	23.25
	C	64.7	20.8	
1964	A	11.2	36.3	
	B	24.0	23.5	22.98
	C	59.5	20.6	
1963	A	9.9	36.3	
	B	27.3	26.3	23.33
	C	62.8	20.0	
1962	A	15.7	36.3	
	B	25.6	27.5	24.89
	C	58.7	20.7	
1961	A	24.0	36.3	
	B	23.2	30.1	27.10
	C	52.8	21.6	
1960	A	28.6	41.7	
	B	9.5		
	C	61.9		

[a] Source: R. L. Polk New Car Registration Statistics, 1960 - 1971.

[b] Source: Consumer Bulletin, Automobile Which ? (British), Car and Driver, Road and Track.

[c] Fuel economy test carried out at 60 mph; a factor of 6.5 mpig was added to correct to 50 mph.

[d] Correction factor, 2 mpig.

[e] Estimate.

[f] Correction factor, 4 mpig.

TABLE 7 ASSUMED EFFECTS OF DRIVING AND ENGINE CONDITIONS ON FUEL ECONOMY VALUES

Condition	Effect (mpig)
Urban Driving	-2
Faulty Tuning	-2
Winter Driving	-1
Total	-5

TABLE 8 MONTHLY AVERAGE HIGH AND LOW AMBIENT TEMPERATURES IN SELECTED CITIES[a]

(Temperatures recorded at airports)

	Los Angeles		Toronto		Montreal	
	High	Low	High	Low	High	Low
January	65	46	30	16	21	6
February	66	47	30	15	23	8
March	67	48	37	23	33	19
April	70	50	50	34	50	33
May	72	53	63	44	64	47
June	75	56	73	54	74	57
July	81	60	79	59	78	61
August	82	60	77	58	75	59
September	81	58	69	51	67	51
October	76	54	56	40	54	40
November	73	50	43	31	39	27
December	67	47	33	21	26	13

[a] Source: Temperature, Humidity, and Precipitation Tables for the World. Published by: Great Britain Meteorological Office.

TABLE 9 CANADIAN AUTOMOBILE PROJECTIONS

	1950	1955	1960	1965	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1985
(A) Automobile Population ($\times 10^9$)	1.91	2.96	4.10	5.28	6.16	6.43	6.60	6.91	7.40[a]	7.74	8.08	8.42	8.76	9.03	9.31	9.59	9.86	11.26
(B) Fuel Economy (mpig)	18[b]	18	18	18	18.3	18.5	17.8	18.3	18.0[c]	17.7	17.5	17.0	16.0	15.5	15.0	14.5	14.0	16.0
(C) Estimated Gas Sale ($\times 10^9$ gal)	1.85	2.85	3.75	3.99	4.76	5.03	5.29	5.34[d]	5.64	5.95	6.25	6.69	7.34	7.84	8.37	8.95	9.59	9.67
(D) Estimated Total Vehicle-Miles ($\times 10^9$ miles) based on E and F																		
(E) Fuel Economy (E = B x C)	33.3	51.3	67.5	71.8	87.1	93.1	94.2	97.7[e]	101	105	109	113	117	121	125	129	134	154
(F) Constant Mileage (F = A x 11 500 miles/year)	22.0	34.0	47.2	60.7	70.8	73.8	75.9	79.5	85.1	89.0	92.9	96.8	100	103	107	110	113	129

[a] Based on S.R.G. projections.
[b] Estimates.
[c] 22% decrease to 1980 with subsequent 11% increase (assumes 1976 NO_x standards implemented).
[d] Projections from 1971 to 2000 based on vehicle-miles and population estimates.
[e] Based on the S.R.G. growth rates after 1971.

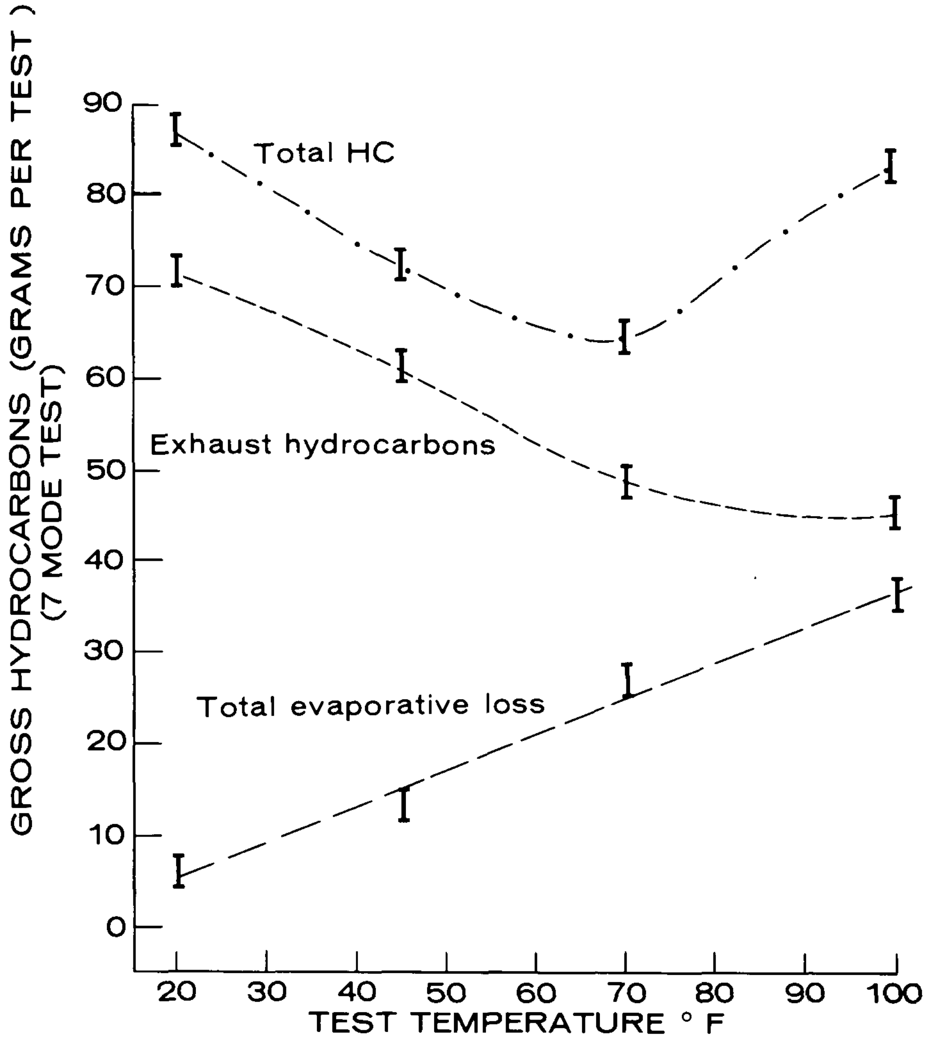

FIGURE 5 EFFECT OF TEMPERATURE ON ENGINE HYDROCARBON EMISSIONS (UNCONTROLLED)

Source : Bureau of Mines
Report # 7291

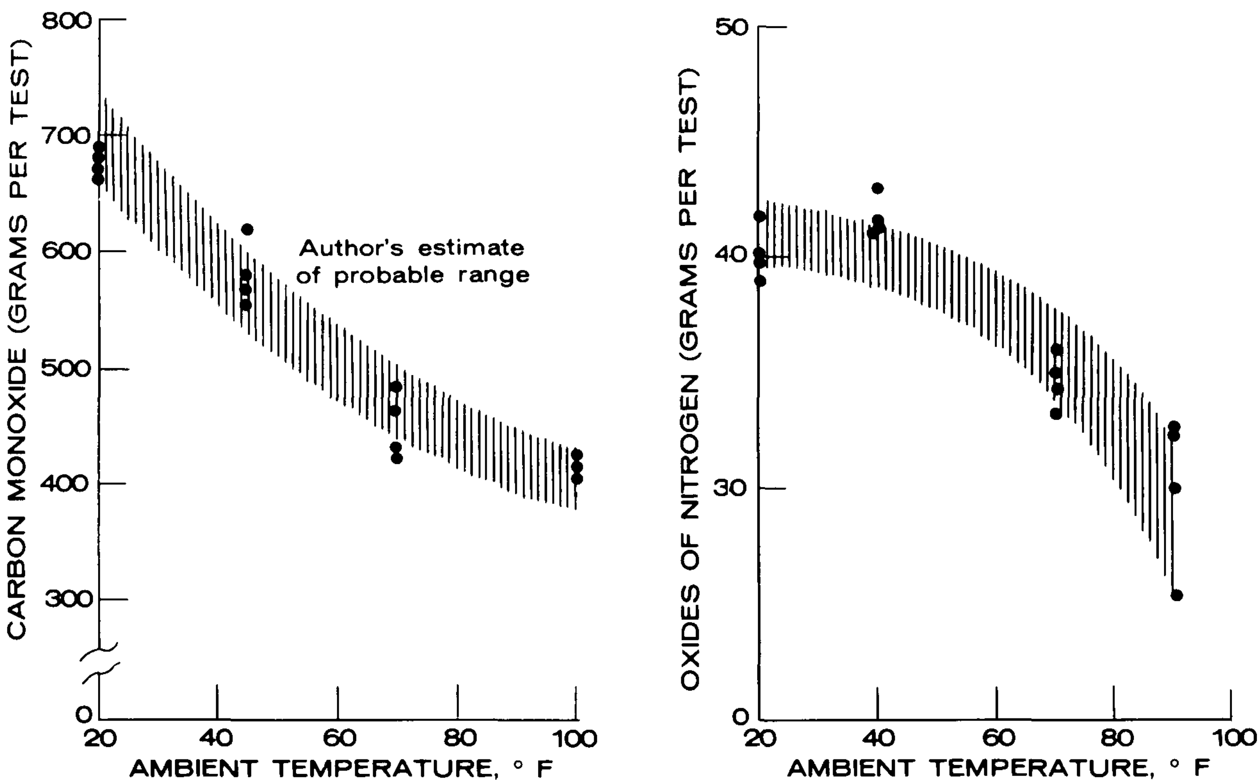

FIGURE 6 EFFECT OF TEMPERATURE ON ENGINE CO AND NO_x EMISSIONS (SEVEN MODE TEST)

Source: U.S. Bureau of Mines Report # 7291 tests were performed on uncontrolled cars; therefore the actual emission levels are of little significance to late model cars. Nevertheless, the trends are indicative of present-day cars excepting those for the evaporative and crankcase emissions, which are now almost completely controlled at normal (70 °F) ambient temperature. Figure 7 illustrates the contribution of the various emission sources for an uncontrolled car to the total output.

Assuming that the percentage change in emissions from the 'normal' temperature to the actual operating temperature is independent of emission control technology, a factor for temperature effect may be calculated. This factor, which is weighted by Toronto-Montreal temperature characteristics, can then be applied to emission factors for HC and CO that were developed at 70 °F. The resultant emission rate will more closely represent the emissions from Canadian automobiles operating on the road. The weighted constant was found to be 1.3. The mathematical function may be written as:

$$\text{Emission Factor (Canada)} = 1.3 \times \text{Emission Factor } (70\,^{\circ}\text{F})$$

This value of 1.3 will be subsequently modified in light of a cold weather testing program presently being undertaken by Environment Canada on the effect of ambient temperatures on automotive exhaust emissions. The following discussion outlines some of the factors that must be considered.

The major influence on the emission formation processes is thought to be the engine block temperature. In Canadian winter conditions the block temperature without any external heat supply usually reaches ambient conditions in an overnight 'soak'. As emissions are increased when the block is not at optimum temperature, the transient warm-up time is an important factor to investigate. This warm-up period depends on engine size, configuration, choking mechanism, and loading.

The effect of the block heater, which increases temperature differences between block and ambience, has yet to be quantified.

However, from available data, an average engine warm-up time is 10 – 15 min at 0 °F (19), and the weekday trip time in a large city averages 18.8 - 19.6 min (6); obviously, even with some nominal stationary warm-up, a significant portion of daily automobile trips are made using a 'cold' engine. This results in higher overall emissions during the colder months for the average car.

Increased emission during the winter can also be attributed to reduced average speeds, increased periods of idling, and poor road traction. Alternately, the reduced mileage accumulation in winter months will somewhat offset these effects.

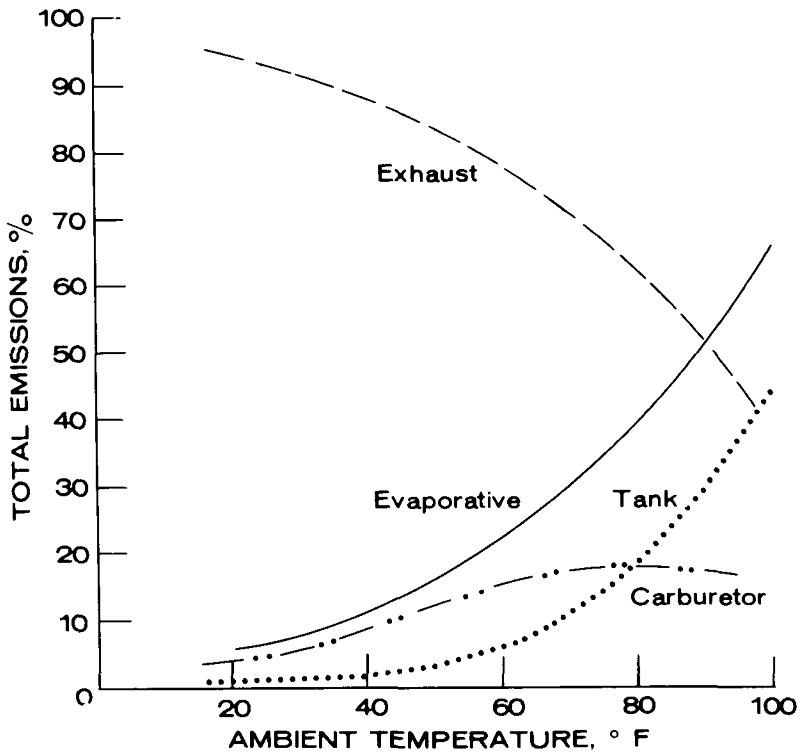

FIGURE 7 CONTRIBUTION OF THE INDIVIDUAL SOURCES OF VEHICLE HYDROCARBON EMISSIONS TO THE TOTAL (16 CARS, THREE 10-lb RVP FUELS) (UNCONTROLLED VEHICLES)

Source: U.S. Bureau of Mines Report # 7291

Thus, until further experimentation clarifies the relative effects of all these variables, the weighting factor for temperature effect of 1.3 is thought to be the best approximation presently available.

5 PROJECTIONS

5.1 Automobile Population

Presented in Figure 8 are Statistics Canada estimates of automobile population (1) from 1940 to the present. Systems Research Group conducted a study into future trends in transportation in Canada (2) the results of which include automobile population projections to the year 2000. The various projection methods used are illustrated in Figure 9. The National Energy Board (NEB) based projection (method 3) was chosen for our purpose since it had the lowest error from Statistics Canada's published figures for the last 2 years. This method indicates that the Canadian automobile population will double within 20 years to reach a figure of nearly 11 million automobiles on the road by 1985.

5.2 Fuel Economy

The implementation of emission controls on automobiles created a fuel economy penalty. An estimate of the magnitude of this penalty from 1968 to 1973 of 7.75 mpg (9.3 mpig) was made by the Environmental Protection Agency (18). General Motors is on public record (19) as stating that they expect no further fuel economy decrease with the statutory 1975 standards; however, the automotive industry has predicted a 5 – 15% penalty with the 1976 nitrogen oxides standards (at the present time the Environmental Protection Agency is re-evaluating the requirement for the 90% control of NO_x as a result of inaccurate air quality measurement equipment). It is anticipated that 50% of the fuel economy loss will be regained by the 'learning process' (20) by 1985 (Table 9). For simplicity the changes are assumed linear from 1976 to 1980 and 1980 to 1985. As the automobile industry is constantly changing its predictions of the effects of controls on fuel economy, these penalty figures will probably require updating as better information becomes available.

5.3 Total Automobile Vehicle-Miles

Estimates of total vehicle-miles were obtained from the fuel economy values for given years in conjunction with the fuel sales for those years. This method of estimating vehicle-miles was used up to 1970 after which time the Systems Research Group (S.R.G.) rates of increase were used. The calculated vehicle-miles are presented in Table 9 and are graphically displayed in Figure 10. Also displayed are S.R.G.'s vehicle-miles projections and an estimate based on a constant miles per year of 11 500 (13) multiplied by S.R.G.'s projected vehicle population.

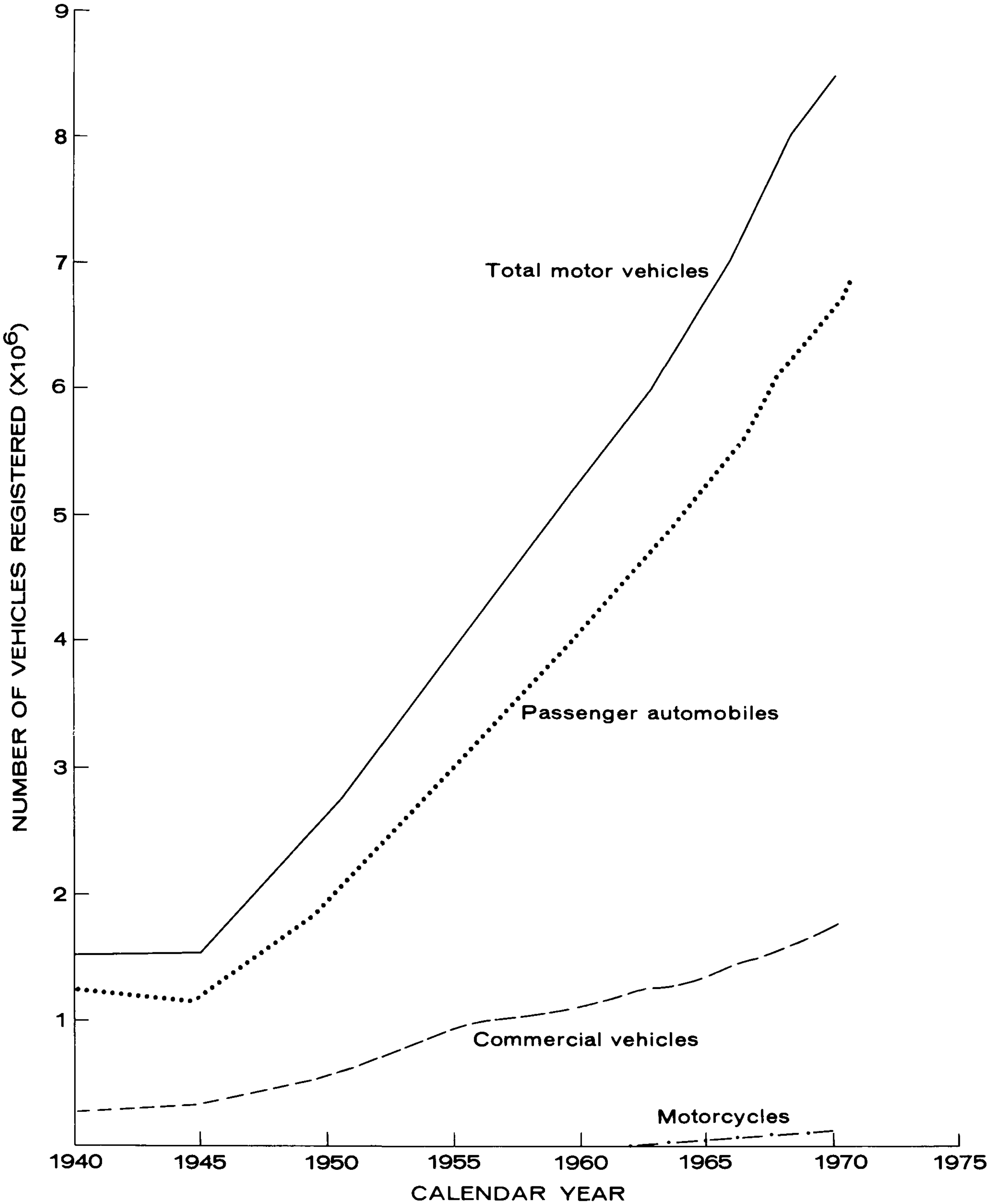

FIGURE 8 VEHICLE REGISTRATIONS IN CANADA 1940-1970

Source : Statistics Canada

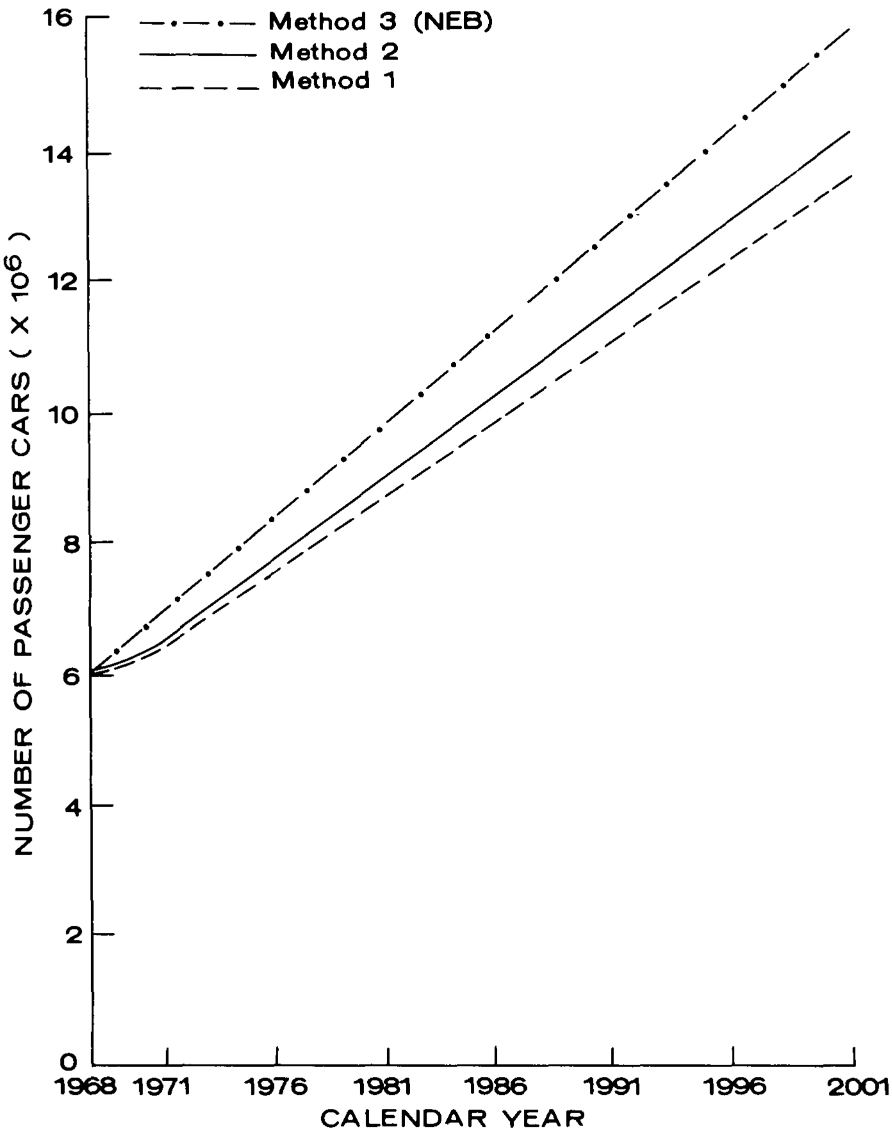

FIGURE 9 PROJECTED NUMBER OF PASSENGER CARS FOR CANADA (IN MILLIONS)

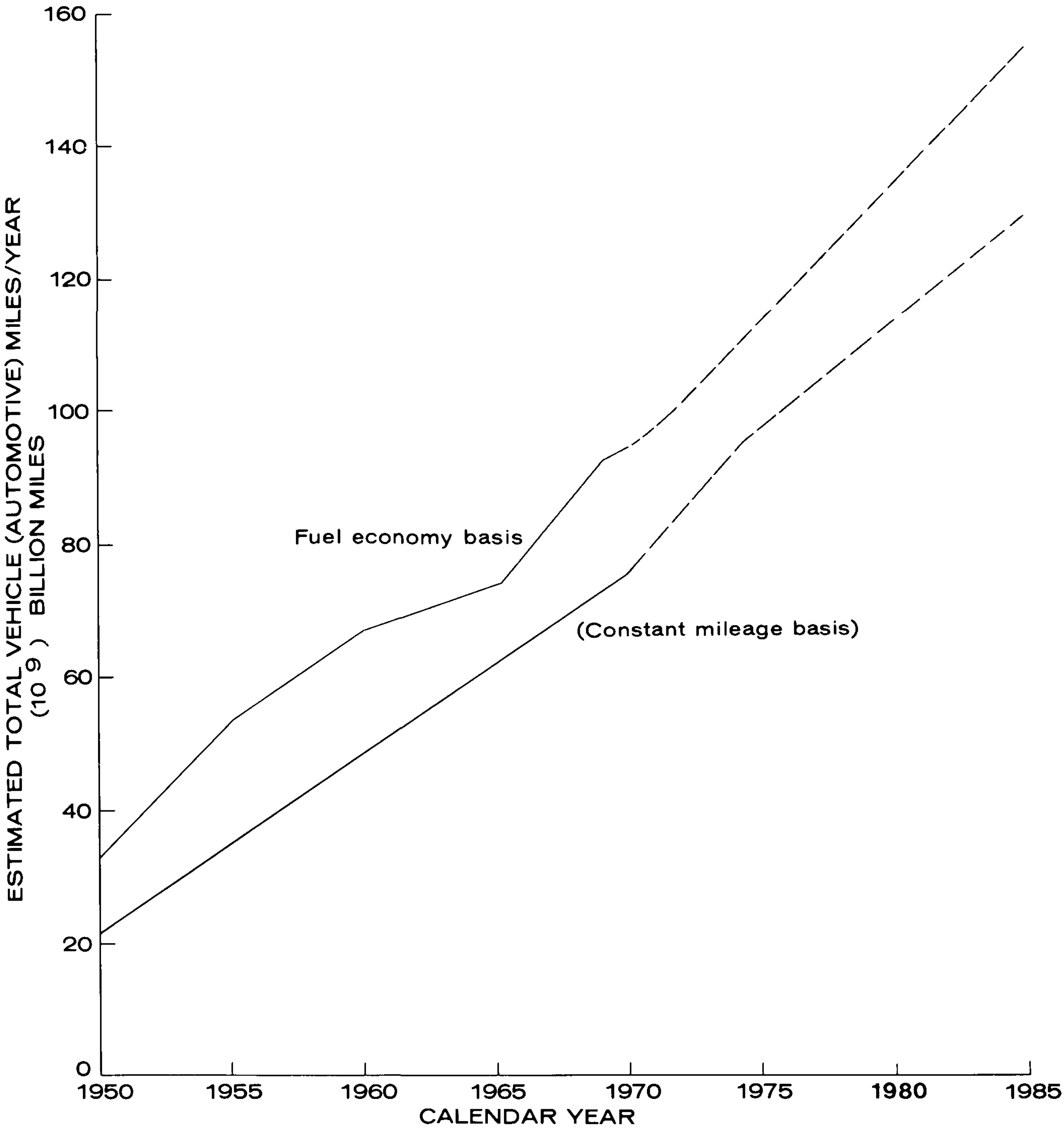

FIGURE 10 ESTIMATED TOTAL AUTOMOTIVE VEHICLE MILES PER YEAR IN CANADA

5.4 Automotive Gasoline Sales

A prediction of automotive fuel sales was calculated using fuel economy and vehicle-miles projections (Table 9). The quantities are strictly the result of mathematical manipulation of the developed projections and the estimated fuel economy changes based on the implementation of the 1976 standards. The calculations (Figure 11) indicate a dramatic increase in total gasoline sales to 9.59 billion gallons in 1980 at which time the demand arising from the assumed increase in fuel economy should stabilize. The 'plateau' region should last approximately 5 years when the increase in total vehicle-miles will precipitate a renewed increase in gasoline sales.

6 EMISSION FACTORS AND TOTAL EMISSIONS CALCULATIONS

The difference in climate population, mix, and driving habits between the United States and Canada deemed it inappropriate to use published emission factors from the Environmental Protection Agency (13) for the Canadian situation. Therefore an effort was made to develop more representative factors for Canadian conditions.

6.1 Canadian Emission Data

To estimate correctly the emission factors for Canadian cars, test data from Canadian 'on-the-road' vehicles had to be obtained. Fortunately, this work has been undertaken by the Ontario Ministry of the Environment. During the last 3 years their testing program has sampled over 9 000 automobiles on Ontario roads. The vehicles were tested by a modified seven mode test, which produced emission values for hydrocarbons and carbon monoxide in parts per million and percentages, respectively.

The Ontario data indicated that average emission rates from vehicles were over their respective standards by approximately 35% for HC and 15% for CO (Figures 12 and 13) (21). The emission rates were significantly higher than those found in similar studies done in California (Figures 14 and 15) (22).

A good estimate of the overall percentage of cars in Canada that will not comply with accepted California 'idle test' standards was produced in a program sponsored by the Alberta Motor Association (23). These figures indicate that at least 60% of Canadian automobiles will not meet 'idle test' standards. Although comparison with a full compliance test is difficult, gross neglect of maintenance on Canadian cars is evident and a significant reduction in air pollution could be achieved through proper car servicing. Thus, it may prove cost effective to legislate and enforce proper tuning of automobiles by means of an emission inspection system.

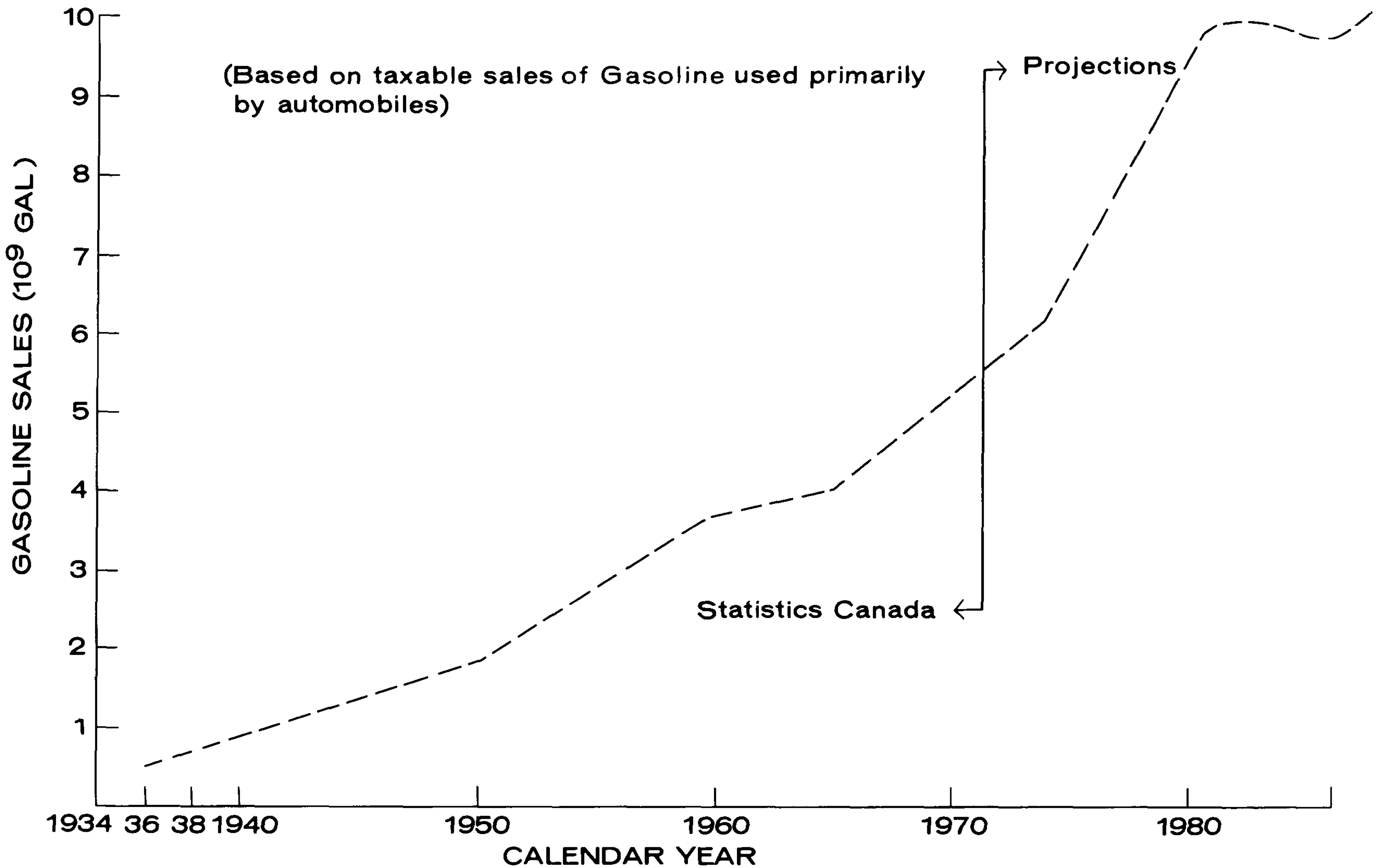

FIGURE 11 GASOLINE SALES BY CALENDAR YEAR IN CANADA (WITH THE 1976 NO_x STANDARDS)

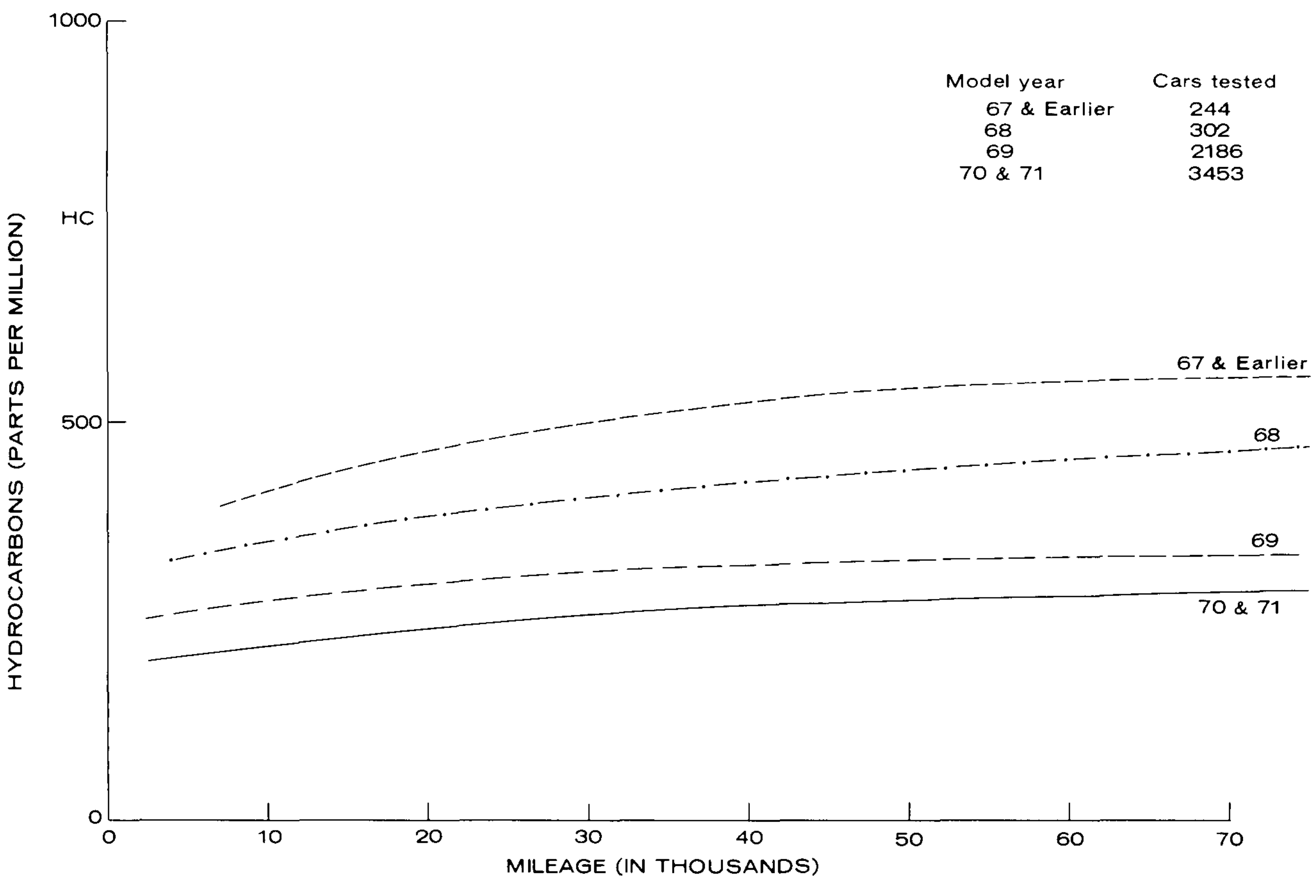

FIGURE 12 HYDROCARBON EMISSION VERSUS MILEAGE (MODIFIED SEVEN MODE TEST)

Source: Ontario Air Managment Branch

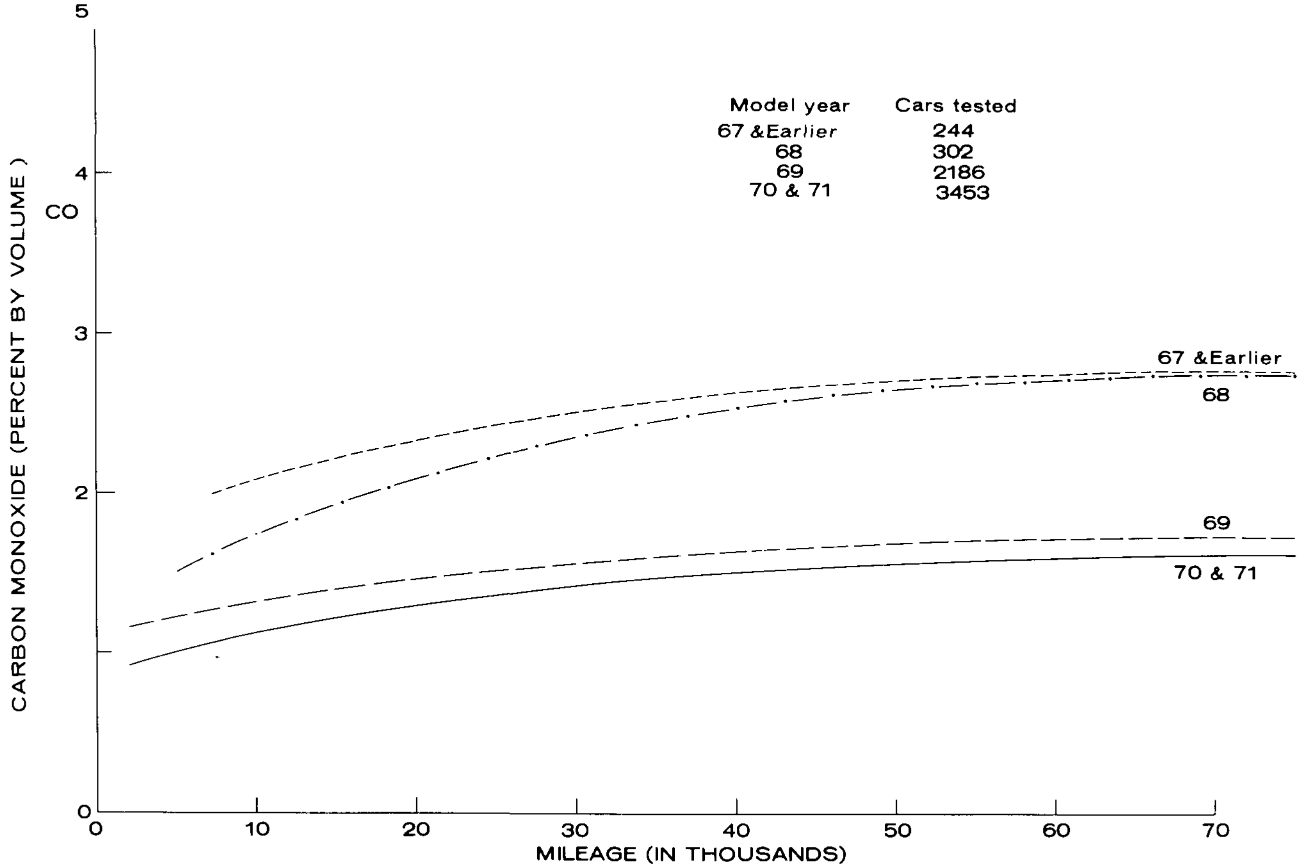

FIGURE 13 CARBON MONOXIDE EMISSIONS VERSUS MILEAGE (MODIFIED SEVEN MODE TEST)

Source : Ontario Air Management Branch

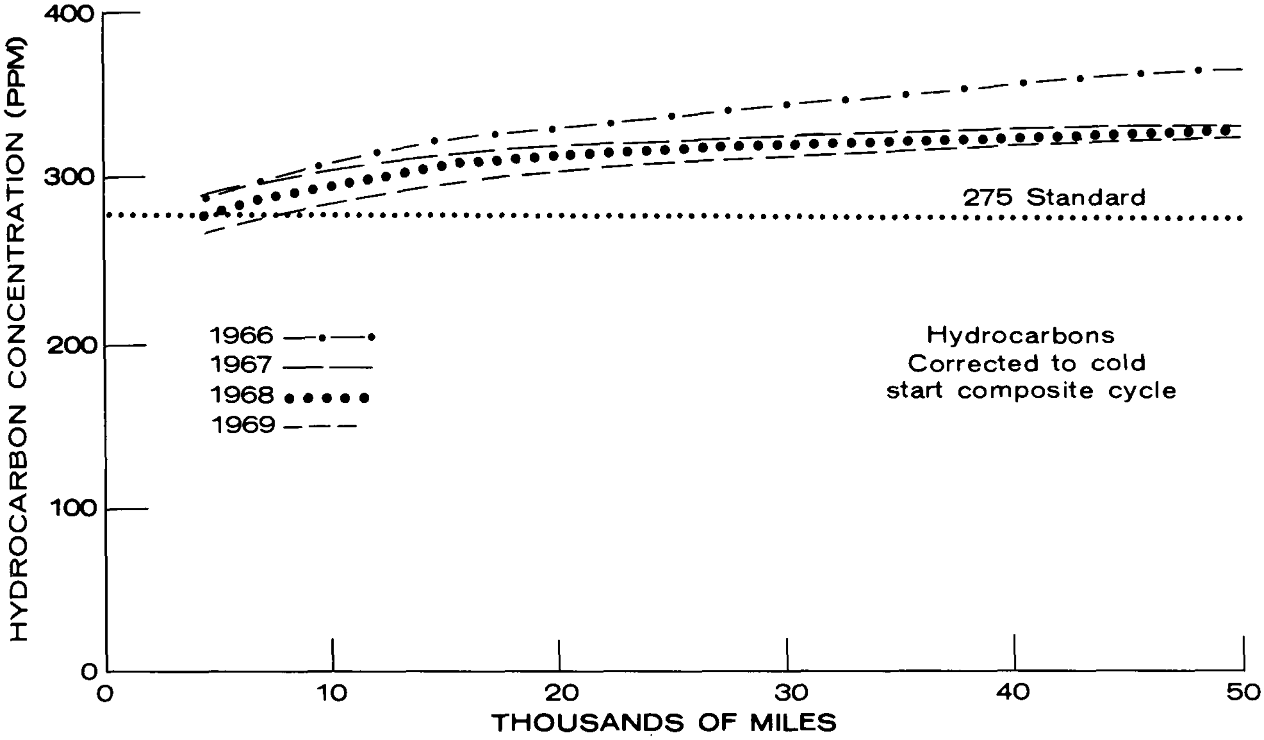

FIGURE 14 HYDROCARBON EXHAUST EMISSIONS VERSUS MILEAGE

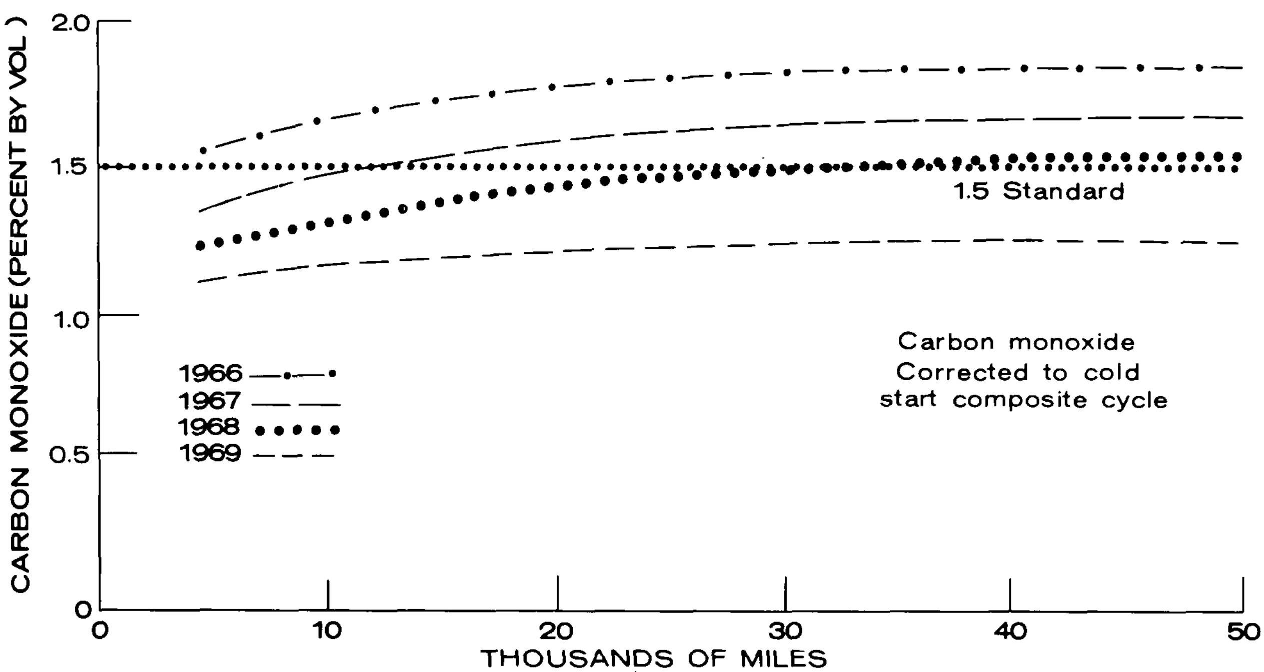

FIGURE 15 CARBON MONOXIDE EXHAUST EMISSIONS VERSUS MILEAGE

Source: California Air Resources Board

Using data obtained from the Ontario testing program, degradation factors for automobiles by model year (Table 10) could be derived. These factors are substantially different from 'compliance deterioration factors', which are indicative only of the operational effectiveness of the emission control systems, and do not consider neglect of engine maintenance.

Cars with advanced emission controls required to meet the 1975/76 standards were assumed to have a degradation rate equal to the 1970 vehicles. This assumption is highly dependant upon the durability of catalyst systems. Their reliability in the prototype models has not yet been proved by the manufacturers, and the prototype to production slip coupled with poor maintenance by the general public could result in higher degradation rates for these catalyst-equipped cars.

6.2 New Car Emission Rates

Table 11 presents the input data of the estimates on the average emissions of new cars by model year (24). Note the rise in NO_x (25) values in the late 1960's and early 1970's resulting from the increase in compression ratios (CR) in most cars. The emission levels quickly dropped as a result of lowering the CR in 1972 models and later vehicles.

6.3 Emission Factor Calculations

The calculations of automotive exhaust emission factors for carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NO_x) can be expressed mathematically as:

$$E_{np} = \sum_{i=n-8}^{n} L_{ip} \cdot d_{ipn} \cdot W \cdot M_{in} + \sum_{i=n-8}^{n} (C_i \cdot V + h_i) \cdot M_{in}$$

where:

E_{np} = emission factor in grams per vehicle-mile for calendar year n and pollutant p

L_{ip} = the 1972 'Federal' test procedure emission rate for pollutant p (grams per mile) for the i^{th} model year at low mileage

d_{ipn} = the vehicle pollutant p emission deterioration factor for the i^{th} model year at calendar year n

M_{in} = the weighted annual travel of the i^{th} model year during calendar year n (the determination of the variable involves the use of the vehicle model year distribution)

W = the cold weather weighting factor for exhaust pollutants (1.3)

TABLE 10 AVERAGE VEHICLE EMISSION DEGRADATION FACTORS [a]

Pollutant	Vehicle Age (Years)	Model Year 1967	1968	1969	1970 and Later
HC	0 - 1	1.00	1.00	1.00	1.00
	1 - 2	1.17	1.17	1.12	1.10
	2 - 3	1.36	1.28	1.20	1.21
	3 - 4	1.44	1.37	1.28	1.24
	4 - 5	1.50	1.43	1.30	1.28
	5 - 6	1.55	1.50	1.32	1.31
	6 -	1.57	1.53	1.34	1.33
CO	0 - 1	1.00	1.00	1.00	1.00
	1 - 2	1.21	1.50	1.21	1.27
	2 - 3	1.37	1.82	1.35	1.47
	3 - 4	1.49	2.03	1.45	1.61
	4 - 5	1.54	2.17	1.52	1.70
	5 - 6	1.57	2.25	1.55	1.76
	6 -	1.58	2.28	1.56	1.78
NO_x	A degradation factor of 1.00 was used for all model years throughout their lifetimes.				

[a] Based on Environment Ontario 'on-the-road' surveillance data. Deterioration above the new-car emission factors in 1972 and later model-year vehicles is not allowed for.

TABLE 11 AVERAGE NEW CAR EMISSION RATES IN CANADA AS A FUNCTION OF MODEL YEAR[a]

(Corresponds to C.V.S.-C 1972 test procedure)

Model Year	Hydrocarbons (g/mile)			Carbon Monoxide (g/mile)	Oxides of Nitrogen (g/mile)
	Exhaust	Blowby	Evaporation		
Pre-1963	17	4.08	2.77	125	3.6
1963	17	0.82	2.77	125	3.6
1964	17	0.82	2.77	125	3.6
1965	17	0.82	2.77	125	3.6
1966	17	0.82	2.77	125	3.6
1967	17	0.82	2.77	125	3.6
1968	7.0	0.00	2.77	71	4.3
1969	7.0	0.00	2.77	71	5.5
1970	4.6	0.00	2.77	47	5.1
1971	4.6	0.00	2.77	47	4.8
1972	3.4	0.00	0.14	39	4.6
1973	3.4	0.00	0.14	39	2.3
1974	3.4	0.00	0.14	39	2.3
1975	0.45	0.00	0.14	4.7	2.3
1976 and later	0.45	0.00	0.14	4.7	0.31

[a]Data obtained from Environmental Protection Agency.

C_i = the evaporative emission rate for the i^{th} model year

V = the cold weather weighting for evaporative emissions (0.5)

h_i = the crankcase emission rate in the i^{th} model year.

The results using this calculation methodology and the raw data described in the foregoing text are reproduced in Table 12.

The effect of the 1973 and 1975/76 standards on the average of emission factors is presented in Figures 16, 17, and 18, which show a major decrease in the pollution emitted per mile by both control strategies.

6.4 Total Emission Calculations

Following the development of data inputs for emission factors and annual mileage travelled, estimates of the total emission of automotive pollutants in Canada by calendar year may be generated. Expressed mathematically the equation is:

$$T_{np} = M_n \cdot E_{np}$$

where:

T_{np} = total weight (grams) of pollutant p emitted in Canada in calendar year n

M_n = total number of vehicle-miles travelled by automobiles in calendar year n

E_{np} = emission factor in grams per vehicle-mile for calendar year n and pollutant p

The results of these calculations are displayed in Table 13 and include the two possible standard alternatives.

In an effort to present the consequences of any regulatory alternative in a clear and more usable form, the emission levels were transformed into an index with 1970 as its base year. The products of these conversions are shown in Figures 19, 20, 21, and 22.

7 CONCLUDING REMARKS

7.1 Accuracy of Calculations

In dealing with any predictive task, a large risk of error is always present. With automobile statistics the likelihood of error is even greater as the population is heterogeneous. The error associated with the emission factors was thought to be allowable for the purposes of

TABLE 12 ESTIMATED EMISSION FACTORS FOR GASOLINE-POWERED AUTOMOBILES OPERATING IN CANADA BY CALENDAR YEAR (g/mile)

	1960	1965	1968	1969	1970	1971	1972	1973	1974	1975	1976	1980	1985
Total Hydrocarbons													
1973 Stds. only	36.0	34.3	31.5	28.3	25.5	22.9	19.3	17.2	14.7	12.5	10.6	5.7	5.5
1975/76 Stds.										11.8	9.4	2.7	0.78
Carbon Monoxide													
1973 Stds. Only	227	227	216	208	193	183	162	147	133	120	109	80	77
1975/76 Stds.										114	94.7	36.1	9.3
Nitrogen Oxides													
1973 Stds. Only	3.6	3.6	3.7	4.0	4.2	4.3	4.4	4.1	3.8	3.6	3.4	2.7	2.3
1975/76 Stds.										3.6	3.1	1.3	0.31

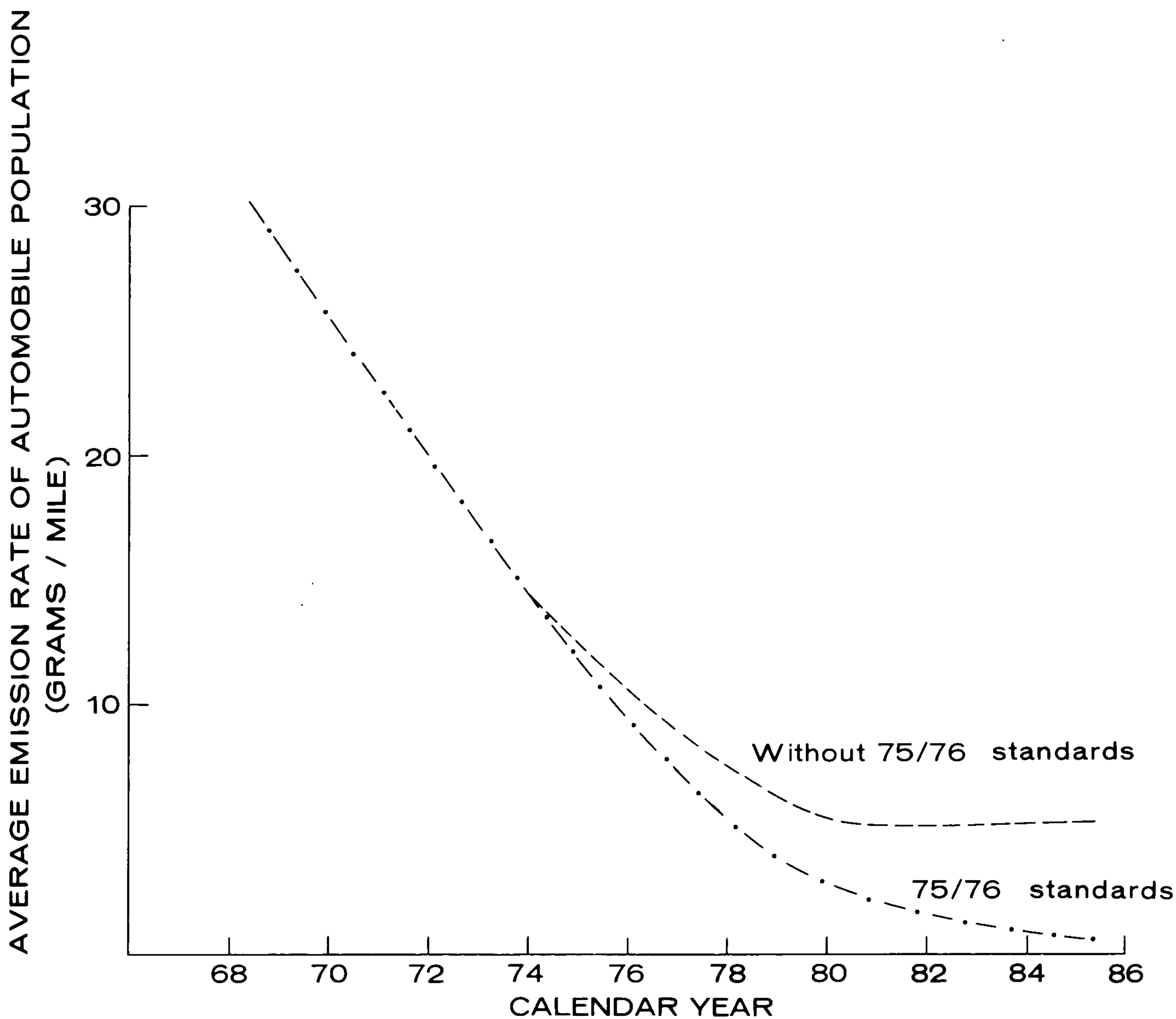

FIGURE 16 HYDROCARBON EMISSION FACTORS

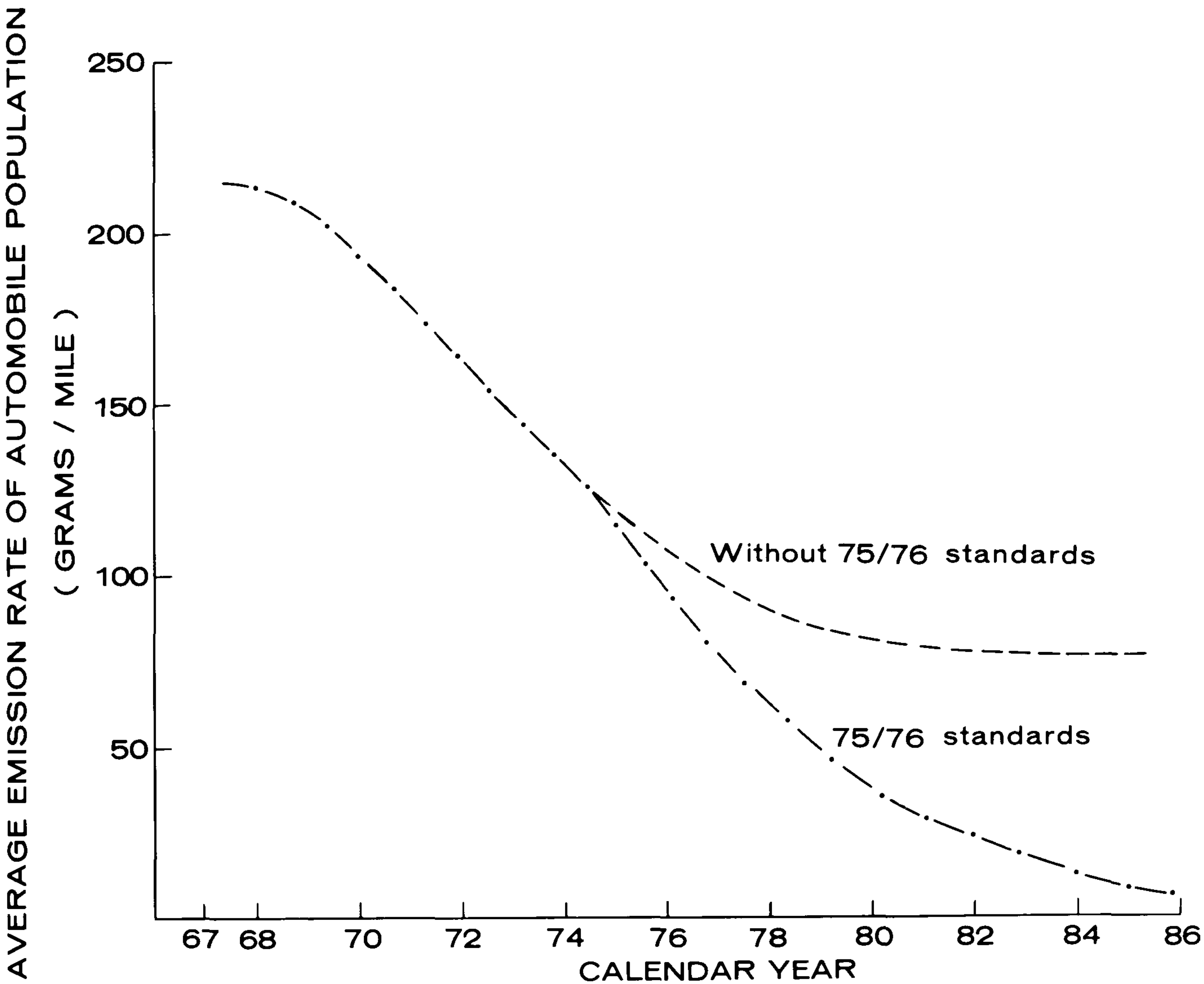

FIGURE 17 CARBON MONOXIDE EMISSION FACTORS

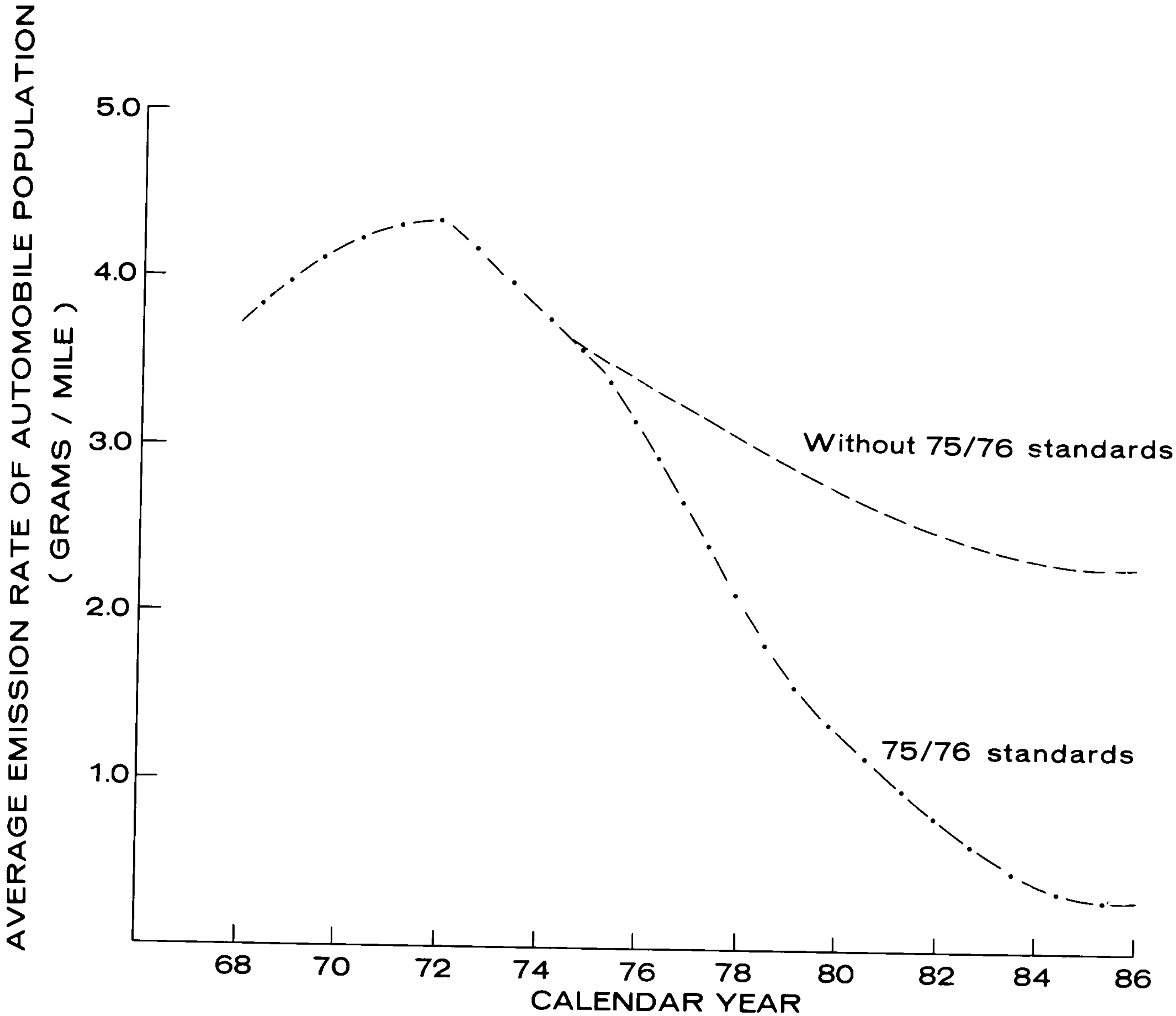

FIGURE 18 OXIDES OF NITROGEN EMISSION FACTORS

TABLE 13 TOTAL AUTOMOTIVE EMISSIONS IN CANADA BY CALENDAR YEAR

	1960	1965	1968	1969	1970	1971	1972	1973	1974	1975	1976	1980	1985
Total Auto Miles (x 10^9 miles)	67.5	71.8	87.1	93.1	94.2	97.7	101	105	109	113	117	134	134
HC Emission Rate (g/mile)													
Without 1975/76 Stds.	36.0	34.3	31.5	28.3	25.5	22.9	19.3	17.2	14.7	12.5	10.6	5.7	5.5
With 1975/76 Stds.										11.8	9.4	2.7	0.78
Total HC Emissions (x 10^9 kg)													
Without 1975/76 Stds.	2.43	2.46	2.74	2.63	2.40	2.24	1.95	1.81	1.60	1.41	1.24	0.76	0.85
With 1975/76 Stds.										1.33	1.10	0.36	0.12
CO Emission Rate (g/mile)													
Without 1975/76 Stds.	227	227	216	208	193	183	162	147	133	120	109	80	77
With 1975/76 Stds.										114	94.7	36.1	9.3
Total CO Emissions (x 10^9 kg)													
Without 1975/76 Stds.	15.3	16.3	18.8	19.4	18.2	17.9	16.4	15.4	14.5	13.6	12.8	10.7	11.9
With 1975/76 Stds.										12.9	11.1	4.8	1.4
NO_x Emission Rate (g/mile)													
Without 1975/76 Stds.	3.6	3.6	3.7	4.0	4.2	4.3	4.4	4.1	3.8	3.6	3.4	2.7	2.3
With 1975/76 Stds.										3.6	3.1	1.3	0.31
Total NO_x Emissions (x 10^9 kg)													
Without 1975/76 Stds.	0.24	0.26	0.32	0.37	0.40	0.42	0.44	0.43	0.41	0.41	0.40	0.36	0.35
With 1975/76 Stds.										0.41	0.36	0.17	0.05

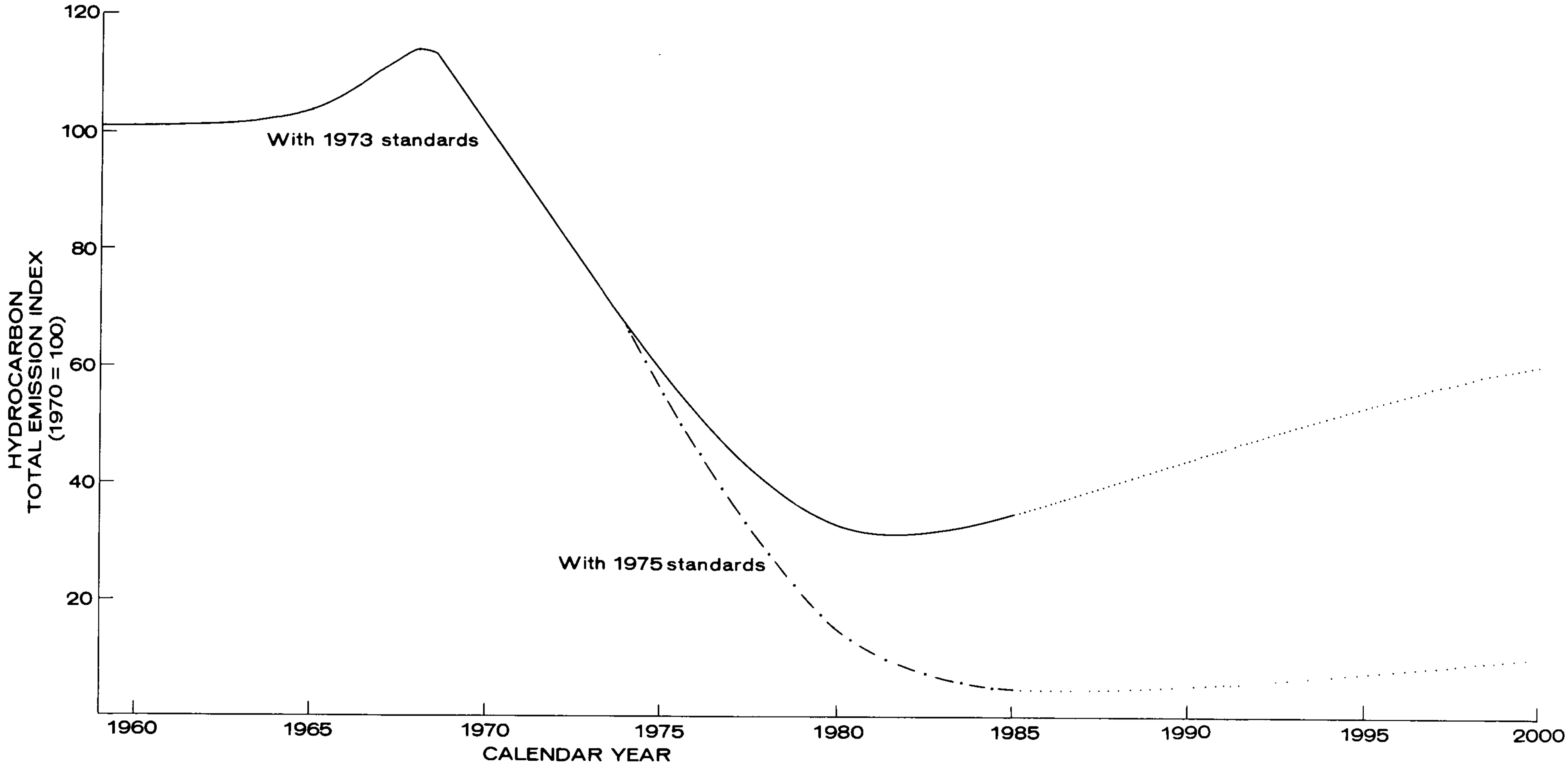

FIGURE 19 HYDROCARBON EMISSION INDEX 1960–2000

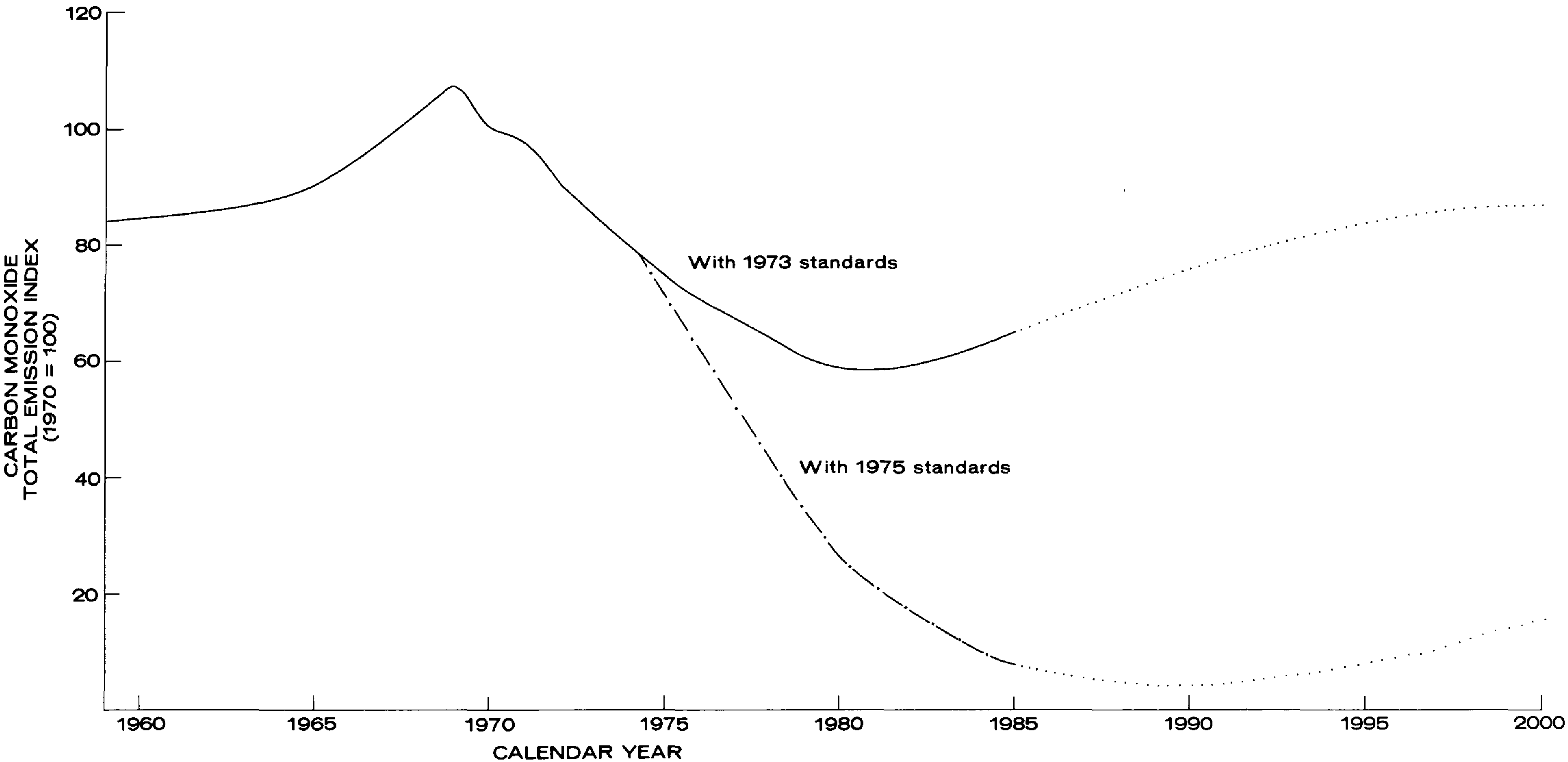

FIGURE 20 CARBON MONOXIDE EMISSION INDEX 1960–2000

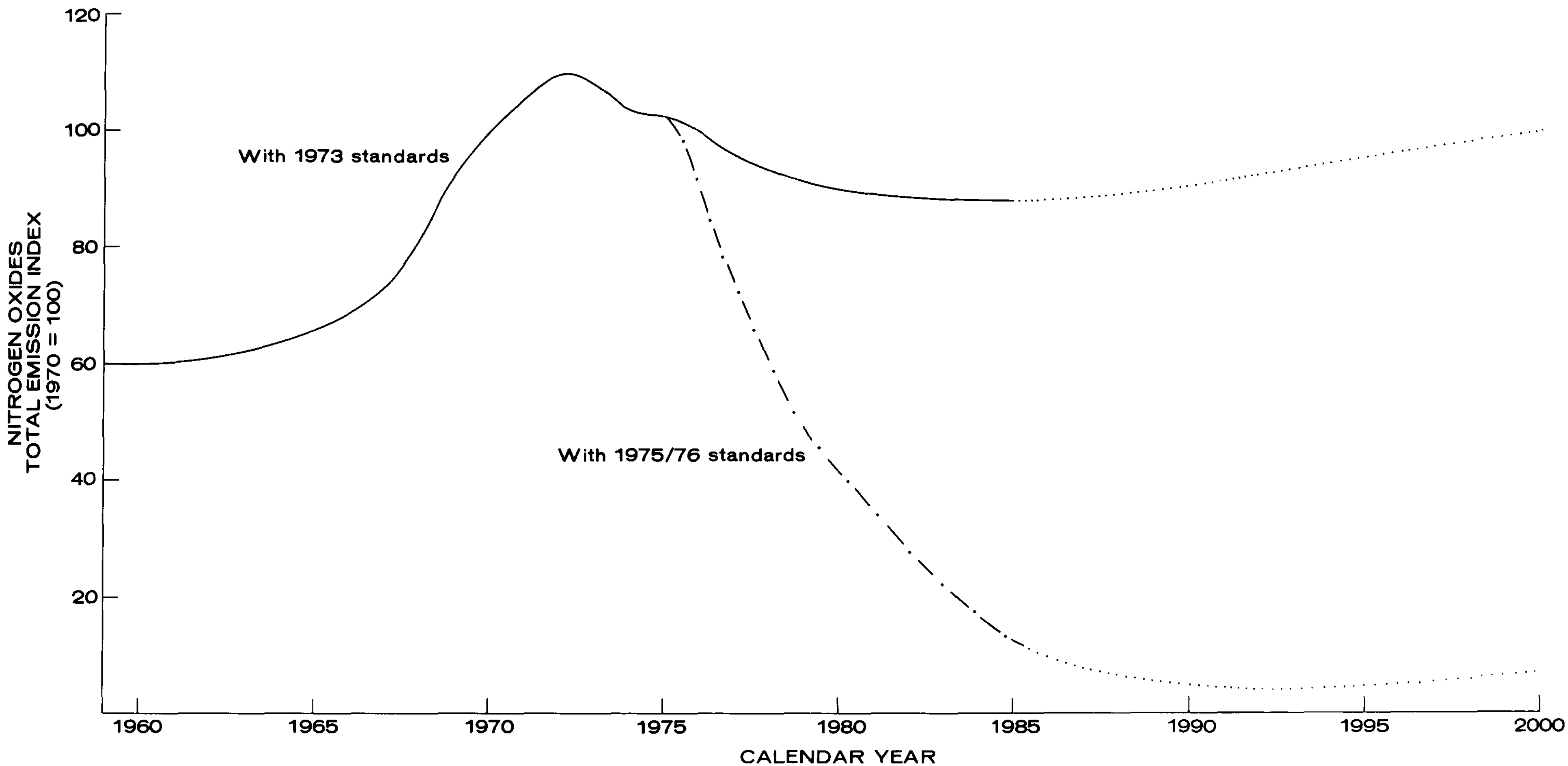

FIGURE 21 NITROGEN OXIDE EMISSION INDEX 1960-2000

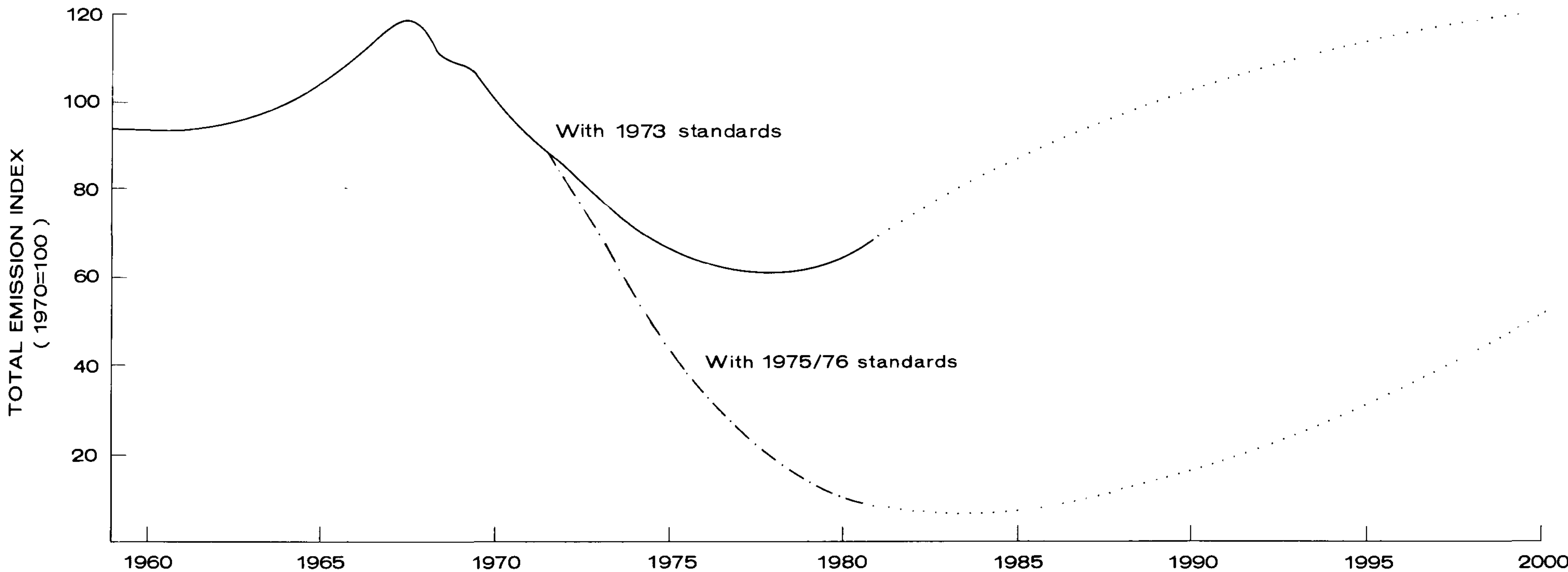

FIGURE 22 TOTAL EMISSION INDEX 1960-2000 (INCLUDES HYDROCARBONS, CARBON MONOXIDE, NITROGEN OXIDE)

this report. In other cases, such as the future deterioration factors, conservative values have been used to present an indication of the best that could be achieved by controls. In the debate that will surely follow this report there will be disagreement. It is hoped that better, more accurate, predictions will ensue.

7.2 Effects of Regulatory Alternatives

The purpose of this report is to ascertain the effects each regulatory alternative would have on total emissions in Canada. The following facts emerge from study of the results.

(1) The Canadian car registrations will roughly parallel the increase in population for the foreseeable future.

(2) This increase in automobile ownership will result in an increase in total vehicle-miles travelled.

(3) Either of the regulatory alternatives will result in a decrease in total pollutants emitted; this will result in an improvement of air quality.

(4) Maintaining the emission standards at the 1973 levels will result in a percentage decrease by 1980 compared with 1970 levels of:

68% for hydrocarbons
41% for carbon monoxide
10% for nitrogen oxides.

(5) Maintaining the 1973 standards will allow a renewed increase in total emissions beginning between 1979 and 1981.

(6) Selection of the 1975/76 standards will result in a decrease in all pollutant levels until 1985 when the reduction from 1970 levels will be:

95% for hydrocarbons
92% for carbon monoxide
87% for nitrogen oxides.

(7) The above percentage reductions represent the best control that can be achieved with the standards proposed.

7.3 Recommendation for Future Investigation

This preliminary study of the Canadian automotive pollution problem has underlined the need for more research in areas of purely Canadian concern, namely:

(1) a major research program aimed at more accurately defining the effects of Canadian climatic conditions on automobile emissions;

(2) a data-gathering program to develop more detailed statistics on automobile operation and maintenance in Canada;

(3) a study on the effect and feasibility of a compulsory vehicle inspection and maintenance in Canada;

(4) a development of a methodology for relating exhaust emission to air quality in urban centers;

(5) an investigation of impact of various control strategies on total emissions and/or air quality on major Canadian centers.

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ADDENDUM

Since this report was completed, several events have occurred that limit the usefulness of the projections presented. Two events of special consequence are outlined here.

(1) In April of this year Mr. Ruckelshaus (26), then the Administrator of the U.S. Environmental Protection Agency, announced a delay of one year in the implementation of the originally proposed (now called statutory) 1975 automobile emission standards. He also announced that interim standards would have to be met in 1975 by the manufacturers, which were more stringent than the present 1973 limits (refer to Table A).

(2) In July (27), the Canadian Government announced that the originally proposed Canadian 1975 standards would not go into effect and that less stringent emission standards would be reproposed for 1975 (refer to Table A).

TABLE A

Emissions, g/mile (CVS-C/H Test)	1973 Canadian and U.S. Standards	1975 U.S. Statutory and Originally Proposed 1975 Canadian Standards	1975 U.S. National Interim Standards	Proposed 1975 Canadian Standards
Hydrocarbons	3.0	0.41	1.5	2.0
Carbon Monoxide	28.0	3.4	15.0	25.0
Nitrogen Oxide	3.1	3.1	3.1	3.1