The pattern of compliance with environmental regulation: evidence from the automobile industry*

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RESUMO

A concentração de poluição atmosférica tem crescido rapidamente nas principais áreas metropolitanas brasileiras como conseqüência de um aumento no uso e na frota de automóveis. Como resposta, padrões de emissões automotivas foram introduzidos por meio do Programa de Controle da Poluição Veicular (Proconve) em 1988. Este trabalho utiliza dados de emissões e características do período 1992-1997 para analisar o ajuste feito pela indústria às normas estabelecidas. Os resultados indicam que o ajuste feito pela indústria não foi homogêneo. Os automóveis grandes tiveram o padrão de ajustamento mais rápido enquanto os carros populares ajustaram suas emissões mais lentamente. Além disso, os carros movidos a gasolina também tiveram suas emissões reduzidas mais rapidamente que os carros a álcool. Concluímos que a regulação estabelecida foi bem-sucedida em reduzir as emissões de poluentes, porém políticas adicionais serão necessárias para criar incentivos para a venda de carros mais limpos e para reduzir as milhas dirigidas. Estas políticas devem ser introduzidas junto com uma política coerente de provisão de meios de transporte público alternativo.

Palavras-chave: economia ambiental, regulação, poluição atmosférica, indústria automobilística.

ABSTRACT

Air pollution concentrations have been rapidly increasing in the major urban areas of Brazil caused mainly by the increasing use of vehicles. In response, mandatory emission standards were introduced by the Programa de Controle da Poluição Veicular (Proconve) in 1988. This paper uses pollution emission and characteristics data to analyze the compliance of the automobile industry with pollution regulation during the 1992-1997 period. We find that the compliance trend adopted by manufacturers was not homogeneous. Larger automobiles had the fastest compliance schedule while popular models adjusted very slowly. Also gasoline-fueled models had a faster adjustment pattern than ethanol cars. We conclude that although the regulation was successful in reducing car emissions, no further regulation was established after 1997. Additional policies that could create incentives for selling cleaner automobiles and driving fewer miles should be introduced together with a coherent policy for providing alternative public transportation systems.

Key words: environmental economics, regulation, air pollution, automobile industry.

JEL classification: L62, Q25, R48.

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1 Introduction

Air pollution is a serious environmental problem in major urban areas. Mobile sources are responsible for a significant fraction of pollution discharge which are generated by vehicles combustion process resulting in hydrocarbons (HC), nitrogen oxides (NOx) and carbon monoxide (CO) emissions.[1] In Europe and the US, motor vehicles typically account for 32-98% of national emissions of CO, HC and Nox. (Small and Gómez-Ibáñez, 1999)

In the case of Brazil, air pollution concentrations have increased rapidly during the last decades. As elsewhere, this expansion has been caused mainly by the increasing size and use of the vehicle fleet. Today, emissions from vehicles are the major source of air pollution in the largest Brazilian cities. In São Paulo, for example, private cars were responsible for approximately 75% of carbon monoxide (CO), 73% of hydrocarbons (HC), 23% of nitrogen oxides (NOx) and 10% of particulate matter (PM) emissions in 1997 (Cetesb, 1998)[2]

Costs associated with high air pollution concentrations in large cities are known to be important. Human health costs predominate, ranging from eye irritations to respiratory problems and increasing cancer rates, all of which induce direct and indirect costs to society.

This increasing air pollution trend generates substantial social costs. Small and Kazimi (1995) estimate health costs from local air pollution caused by the average on road automobile in Los Angeles in 1992 to be $0.03 per vehicle mile. In Brazil, Seroa da Motta and Mendes (1995) estimate that a reduction of 7% in the mortality rate from respiratory diseases could be achieved in São Paulo, if particulate levels were reduced to minimum legal standards. They also estimate the health costs associated with concentration levels in excess of air pollution standards, finding a loss of approximately US$ 700 million per year in the early 1990s.

Even when consumers can perceive individual emission damage, they are unable to reduce the aggregate social emission costs. In the presence of this negative externality, environmental regulation is required.

1 HC emissions result when fuel molecules in the engine do not burn completely. They react with nitrogen oxides (NOx) and sunlight to form ground-level ozone which irritates eyes and aggravates respiratory problems. CO emissions is also a product of incomplete combustion and can have severe health consequences due to its effect on the flow of oxygen to the blood.

2 According to Cetesb (1998), the air quality in the São Paulo metropolitan area is considered to be below the human health minimum standard for at least 25% of the days in a year.

The Brazilian government adopted such a regulation scheme by implementing the Vehicle Air Pollution Control Programme (Proconve) in 1988. It established maximum pollution emission standards (in grams per kilometer) for new vehicles entering the market.

This paper intends to analyze the evolution of average emissions in the Brazilian car fleet after the Proconve regulation and the pattern of compliance that occurred. The program was divided in two phases: a first phase occurring from 1988 to 1992 and a second phase from 1992 to 1997 Due to data limitations, we are only able to analyze the 1992-1997 period. Nevertheless, this was an especially interesting period since other governmental initiatives have affected the car market and consequently the emission pattern of new automobiles.

We focus our analysis on the relationship between emission control and government policies. Since there was a substantial time of five years for adjustment, we believe that other economic policies have influenced the timing of technological adaptation. We relate the pollution control strategy to three changes in the Brazilian automobile market: changes in the tax structure between gasoline and ethanol cars, trade liberalization with allowance for imported car models and the introduction of "low-price models" (" popular cars").

Our analysis is based on emission data recorded from laboratory tests undertaken by the São Paulo Environmental Agency (Cetesb) that electronically measure emissions of HC, CO and NOx for each car model along with the model's characteristics.

We use an approach previously explored in White (1982) and Kahn (1996), defining a pollution emission production function and estimating a cross-section regression to investigate the evolution of manufacturers compliance with pollution regulation.

The evolution of emission adjustment from 1992 to 1997 is examined by comparing the trend between gasoline and ethanol cars and small, medium and large cars for all three pollutants. Controlling for engine size, horsepower, fuel type and nationality we estimate average percentage reductions in emissions for each year from 1992 to 1997 Additionally, using dummy variables for fuel type and nationality, we compare average emissions of gasoline and ethanol cars and national *vis-à-vis* foreign car models.

The rest of this paper is structured as follows: section 2 presents the Brazilian regulatory framework for car pollution control; section 3 describes our database and model characteristics and section 4 presents the econometric results. Concluding remarks and policy recommendations are discussed in Section 5.

2 Environmental regulation and the Vehicle Air Pollution Control Programme (Proconve)

The Brazilian government signed a protocol with the automotive industry in 1986 introducing pollution emission standards for all new automobiles. The Vehicle Air Pollution Control Programme (Proconve), which was turned into a law in 1993, was the first attempt to control pollution emissions from automotive sources in Brazil. The Proconve classified vehicles in three segments: light vehicles for passenger use, light vehicles for commercial use and heavy vehicles. For each group, a specific adjustment schedule was established.

Our analysis focuses on the pattern of compliance of light vehicles which are responsible for approximately 80% of total emissions of CO and 82% of total emissions of HC in the São Paulo metropolitan area. (Cetesb, 1998) The adjustment for light vehicles was designed with three phases. In Table 1 we present the standards for the three pollutants in comparison with the prevailing US standards. Phase one was implemented gradually between 1988 and 1991 with a loose target and specific adjustment schedules for some car models which were allowed a six-month period of adjustment.[3]

Phase 2 started with the limits imposed for 1992 until 1997. Although the program did not impose directly a specific technology for the standard attainment, most of emission reductions were attained with the introduction of electronic injection, carburetors with electronic assistance and catalytic converters.

The third phase which started in 1997 aimed at inducing manufacturers to apply the best technology available for emission control. (Ibama, 1998) Nevertheless, no further standards were created for pollution control.

Table 1
Emission Standards for New Cars in Brazil and the United States (g/km)

	Carbon Monoxide (CO)		Hydrocarbons (HC)		Nitrogen Oxide (NOx)	
Year	Brazil	U.S.	Brazil	U.S.	Brazil	U.S.
1988	24.0	2.0	2.1	0.26	2.00	0.62
1992	12.0	2.0	1.2	0.26	1.40	0.62
1997	2.0	2.0	0.3	0.26	0.60	0.62

Source: Brazilian National Environmental Code (Conama) resolution No. 18, 1986 and Kahn (1996).

3 For specific car models the first target was established for January 1989 instead of June 1988.

All new car models sold in Brazil after 1988 have been subject to laboratory testing by Cetesb. Tests are undertaken according to engine groups. An engine group is defined as car models that are produced by a single manufacturer with the same emission characteristic.[4] The testing procedure works as follows: the manufacturer sends the prototype engine to Cetesb in order to be tested for CO, HC, NOx, CHO and evaporative emissions. If the engine complies with the prevailing standards, the Brazilian Environmental Institute (IBAMA) issues a license for commercialization. After that, the group of cars produced by the same manufacturer that uses the tested engine can be sold in the market.

Licenses for commercialization are issued for a specific year and can be renewed if the car model did not suffer any technological change. The manufacturer is responsible for any variation in the emission level of a car that had its license renewed. If a technological change occurs, the model is tested again and in case of approval a new license is issued.[5]

The Proconve protocol was successfully implemented from 1988 to 1997 and average emission levels of new cars sold in Brazil decreased considerably, as can be observed in Table 2.

Table 2
Average Emission Level for New Automobiles

Year	Fuel type	CO (g/km)	HC (g/km)	NOx (g/km)
Prior to 1980	Gasoline	54	4,7	1,2
1986-1987	Gasoline	22	2,0	1,9
	Ethanol	16	1,6	1,8
1988	Gasoline	18,5	1,7	1,8
	Ethanol	13,3	1,7	1,4
1992	Gasoline	6,2	0,6	0,6
	Ethanol	3,6	0,6	0,5
1997	Gasoline	1,2	0,2	0,2
	Ethanol	0,9	0,3	0,3

Source: Cetesb (1998). Average emissions are weighted by production of each car type. The 1986/1987 period represents the emission level prior to the Proconve implementation.

4 For example, Gol and Parati, produced by VW, belong to the same engine group.

5 An additional consideration was introduced in the Proconve program in 1995. Since automobile use and depreciation can lead to significant emission increases over time, an additional regulation was introduced obliging manufacturers to adopt a technology that would guarantee the attainment of the emission standard for at least 80,000 km. The adoption of such a technology was designed in order to be implemented gradually until December 2002.

It can be seen that emissions decreased, on average, by approximately 90% between 1986/87 and 1997. Nevertheless, this adjustment differed among pollutants, between gasoline and ethanol models and national and foreign cars. It is important to note that average emissions of CO and HC were already decreasing prior to the Proconve implementation and it is hard to separate natural technological innovation from regulatory effects.[6]

3 The automobile market and government policies during the nineties

Additionally to prior technological development, the pattern of compliance with the environmental regulation was directly influenced by policy changes. Several government policies have shaped the size and the composition of the Brazilian car fleet during the nineties. These policies had substantial effects on the pattern of pollution control adopted by automobile manufacturers. We focus our analysis on the relationship between the response to the environmental regulation and two specific policy changes, namely: the phase out of the ethanol fuel program and the modifications occurred in the automobile value-added tax.[7]

Car taxation in Brazil is recognized as very high, varying from 23% to 33% of the average price. Apart from two minor social contributions, it consists mainly of two parts, a state circulation value added tax (ICMS) and a federal industrial value added tax (IPI). The highest tax burden comes from the IPI, which is progressive with the vehicle power (measured in engine size and horsepower). Differentials among tax brackets have been changing in the last decade and sectoral policy objectives have led to changes in the tax rate across different fuels and engine sizes, as can be observed in Table 3.

The first tax differentiation adopted in Brazil was for ethanol and gasoline cars. To promote the sale of pure ethanol cars, the government relied on very aggressive fiscal and credit policies.[8] Ethanol fuel prices were set favorably in relation to gasoline (reducing its relative price) and ethanol cars were also sold with lower sale tax rates and better financing schemes. Nevertheless, in the late 1980s, the continuous decline in international oil prices and the severe public

6 See White (1981) for a similar point on the effect of the U.S. automotive emission control program.

7 For further analysis of the effects of government policies on the automobile market during the nineties see De Negri (1999).

8 The Brazilian National Alcohol Programme (Proalcool), appeared indirectly as a response to the first oil crisis in the seventies with the addition of ethanol to gasoline. Later, with the second oil crisis, Brazil initiated a further phase of Proalcool, aimed at the sale of pure ethanol-fueled cars.

deficits faced by the Brazilian economy caused a cut in ethanol subsidy mechanisms. The fuel parity was substantially reduced and subsidies for producers were also dramatically cut. Ethanol car sales declined dramatically and almost disappeared in the beginning of the 1990s.[9]

Car taxation has also been used in Brazil to achieve sector development policy objectives. Since 1986 the Brazilian government has differentiated the industrial value added tax (IPI) charged on automobiles by fuel and horsepower, imposing a higher tax for cars above 100 HP, as can be seen in Table 3. This differentiation was accentuated with the introduction of the "carro popular" (up to 1000 cc) in 1990. The tax rate for the "carro popular" was reduced from 14% in 1992 to 0.1% in 1993 as an attempt to reverse the decline trend in car sales.[10] The tax was then increased to 8% in 1995 and to 13% in 1997 As it can be seen, these tax reductions are more substantial than those offered for ethanol cars.

Table 3
Evolution of the Industrial Value Added Tax (IPI) for Automobiles in Brazil (in %)

Year	Up to 1000cc Carro Popular	More than 1000cc, but up to 100 HP Gasoline	More than 1000cc, but up to 100HP Ethanol	More than 1000cc, over 100 HP Gasoline	More than 1000cc, over 100 Hp Ethanol
1988		45	40	50	45
1989		33	28	38	33
1990	20	37	32	42	37
1991	20	37	32	42	37
1992	14	31	26	36	31
1993	0.1	25	20	30	25
1994	0.1	25	20	30	25
1995	8	25	20	30	25
1996	8	25	20	30	25
1997[a]	13	30	25	35	30

Source: Anfavea (1999).

[a] Tax implemented in November, 1997.

Additionally to value added tax differentiation, a reduction of 5% on the industrial value added tax levels was offered for large cars (between 100 and 127 horsepower) that adopted

9 Although pure ethanol cars were relatively cleaner than gasoline-fueled vehicles for certain pollutants, they generally require a higher volumetric fuel consumption per mile traveled of approximately 15 to 20% depending on the model.

10 In this case, the state value-added tax (ICMS) was also differentiated for "popular cars" for certain periods.

fuel injection devices. This tax incentive resulted in a complete introduction of fuel injection devices from 1992 onwards.[11]

Emission reductions were firstly accomplished through the introduction of catalytic converters which was made possible due to the regulation of the ethanol content in the gasohol mixture at a constant 22% level.[12] The stability of the mixture used for automobile fuel allowed the automotive industry to accelerate the introduction of technological innovations.

4 A simple model of car emissions and characteristics

Vehicle emissions generated by combustion processes depend not only on the type of fuel used, but also on mechanical characteristics such as: engine size, horsepower, type of transmission, type of carburetor and electronic injection and the presence of a catalytic converter. Technological change also affects emissions through years. Therefore, controlling for miles driven, we would expect older cars to have higher emission levels than newer models.

In order to explain the difference in emissions across different car models, we follow White (1982) and Kahn (1996) and assume that a new car *i* has a production function for pollution emissions represented by,

$$E_{ij} = f(Year_i, X_i) \tag{1}$$

where E_{ij} is the emission of pollutant *j* generated by car *i*, $Year_i$ is the car model year and X_i is a vector of automobile characteristics that include horsepower, engine size, revolutions per minute (RPM) and fuel type.

This function relates engineering characteristics to pollution emissions in grams per kilometer. For a specific year, a different combination of characteristics such as electronic injection, horsepower, catalytic converter and others will generate a given amount of pollution for CO, HC and NOx. Thus the year dummy captures different technological parameters that are not taken into account by the other variables.

Based on this simple model we use data from 1992 to 1997 to analyze the pattern of adjustment that occurred towards the 1997 emission standard. Using a cross-section of car mod-

11 It is important to note that the electronic injection subsidy worked equivalently to a sale tax on dirty large cars.

els tested by Cetesb between 1992 and 1997 we regress the emission of pollutants (CO, HC and NOx) as a function of year dummies controlling for engine size, horsepower, revolutions per minute and fuel type. The transformed coefficient on year dummies generates the percentage reduction on emissions that was undertaken by each car group with respect to the base year 1992.

We perform two types of comparisons: the pattern of compliance chosen by manufacturers with respect to gasoline and ethanol cars, and controlling for fuel type we analyze the emission control trend undertaken by cars in different size groups: small, medium and large cars. This analysis is chosen based on the pattern of tax differentiation that was introduced by the Brazilian government in 1992.

In each of the two groups of regressions we also introduce a dummy for imported cars in order to be able to distinguish between national and foreign pollution control technology. Therefore, controlling for other characteristics, we are able to compare average emissions for national and imported cars.

5 The data

Our data were obtained from laboratory tests undertaken by the São Paulo Environmental Agency (Cetesb) which recorded electronically the emissions of HC, CO and NOx for each car model along with the model's characteristics.[13] Since Cetesb only tests auto engines and emissions by family type, the same emission test is usually employed for cars with the same engine, but with different weight, size and maximum speed. This introduces a problem if we want to explain variation in emissions as a function of these characteristics. We opted for using a single observation from each engine family tested and excluding varying characteristics such as weight and size.

Even for a model of the car family, usually there is more than one test for each pollutant. Following the CETESB procedure, we calculated an average of the tests and used the result as the corresponding emission level.

12 The law accepts a variance of 2% and later accepted a content of 24%.

13 See Ibama (1998) for more details on the testing procedures.

Other characteristics such as number of cylinders and transmission type are not used since they are almost uniform in Brazil (where most cars have four cylinders and use manual transmission). Information on catalytic converters is also available, but only for part of the database and consequently could not be used. The variables left for inclusion in our analysis with enough precision are fuel type, engine size, horsepower, rpm and the year of the test.

We merged the data available from Cetesb with a database that records sales of each car model in Brazil. We opted for including in our regression only car models that had at least 50 units sold during the 1992-1997 period. In order to categorize national and imported cars, we considered all cars produced in Argentina by the Autolatina (former association of Volkswagen and Ford) and Fiat as national cars due to the similarity of models and consequently technology.[14]

6 Econometric results

Although we have emission tests for six years, it is hardly possible to follow specific car models through the entire period since names and characteristics change and some models go out of production. Therefore, due to this unequal distribution of observations across time, it is not possible to undertake a panel-data analysis. We opted for pooling all observations controlling for variables that influence emissions such as engine size, horsepower, fuel type, nationality and year.

The emission compliance trend is analyzed by fuel type (gasoline and ethanol) and car size (small, medium and large). The analysis is undertaken for three pollutants CO, HC and NOx using a semi-log approximation to equation (1),

$$\log e_i = \beta_0 + \beta_1 hp_i + \beta_2 eng_i + \beta_3 rpm_i + \beta_4 dgas_i + \beta_5 dfor_i + \sum_{k=1}^{5} \gamma_j dyear_{ik} + \varepsilon_i \qquad (2)$$

14 It would be incorrect to consider the same car produced in Brazil and Argentina with the same technology as having different characteristics embodied in the imported dummy variable.

where for each car model i, e is the emission, *hp* is horsepower, *eng* is engine size, *rpm* is rotations per minute, *dgas* is a dummy variable equal to one for gasoline fueled cars, *dyear* are dummies taking the value 1 if the car was tested in that year and zero otherwise and ε is the zero mean error term.

Based on this semi-logarithmic specification, the coefficient estimate gives us the percentage change in average emissions due to a unit change in the independent variable. Note that for the dummy variables, the correct expression for this percentage change is given by $e^{\gamma} - 1$. Therefore, the results are discussed based according to the transformed coefficients.[15]

6.1 Compliance schedules and emission trends by fuel type

The results for the regressions describing the pattern of compliance by fuel type are presented in Table 4. We estimate six regressions that fit equation (1) by OLS for all three pollutants and for both fuel types: gasoline and ethanol. The covariates included in the final specification are engine size, horsepower, nationality dummy variable (which equals one for foreign cars) and year dummies for the 1992-97 period.

In general, all equations have a satisfactory fitting with an R^2 varying between 0.54 and 0.11, with a better fit for the CO and HC regressions. The F-test reject the null hypothesis of the coefficients being jointly zero for all estimated equations and most coefficients are statistically significant with the expected sign.

As expected, for most pollutants and fuels types, emission levels rise with engine size. However, after controlling for engine size, test year and nationality, results indicate that emissions decrease with larger horsepower. This could be due to the high performance fuel injection technology used in luxury high-powered car models.

15 It is also important to point out that all year dummy coefficients represent variations against 1992.

Table 4
OLS Estimates of CO, HC and NOx Emissions by Fuel Type Automobiles

	Log CO		Log HC		Log Nox	
	Gasoline	Ethanol	Gasoline	Ethanol	Gasoline	Ethanol
Constant	15.798	0.3222	-0.7494	-0.0932	-0.3421	-0.2747
	(0.0564)**	(0.2754)	(0.0509)**	(0.1961)	(0.0628)**	(0.3291)
Engine size	0.3505	21.225	0.0391	0.5536	0.0729	-0.9264
	(0.0517)**	(0.2999)**	(0.0335)	(0.2096)**	(0.0401)	(0.3639
Horsepower	-0.0083	-0.0297	-0.0021	-0.0157	-0.0040	0.0133
	(0.0007)**	(0.0036)**	(0.0005)**	(0.0025)**	(0.0006)**	(0.0042)
Imported (1=yes)	-0.8173		-0.6279		-0.6160	
	(0.0313)**		(0.0247)**		(0.0313)**	
1993 test	0.0090	-0.0170	0.0058	0.0036	-0.0824	-0.0354
	(0.0581)	(0.0585)	(0.0504)	(0.0471)	(0.0635)	(0.0858)
1994 test	-0.1277	-0.0435	-0.1132	0.0491	-0.0470	0.0982
	(0.0675)	(0.0672)	(0.0567)*	(0.0521)	(0.0673)	(0.0962)
1995 test	-0.2743	-0.0697	-0.2809	0.0005	-0.1076	-0.0496
	(0.0503)**	(0.0560)	(0.0471)**	(0.0423)	(0.0577)	(0.0759)
1996 test	-0.4193	-0.3365	-0.3702	-0.1311	-0.1712	-0.1873
	(0.0514)**	(0.0652)**	(0.0464)**	(0.0469)**	(0.0569)**	(0.0780
1997 test	-10.365	-16.313	-0.8077	-10.788	-0.7476	-0.8779
	(0.0505)**	(0.0668)**	(0.0448)**	(0.0449)**	(0.0578)**	(0.0862)
Observations	2665	647	2665	647	2665	647
Adjusted R^2	0.5455	0.4385	0.4465	0.4176	0.3795	0.1137

Notes: White heteroscedasticity consistent standard errors on(/in?) parentheses. The coefficient for imported ethanol is not available since there are no imported ethanol cars. * Statistically significant at the 5% level. ** Statistically significant at the 10% level.

Another expected result is that imported cars generate, on average, lower emissions than national cars. The negative coefficient found on the imported dummy confirms this result and it is significant for all three pollutants with a larger difference between national and foreign car CO emissions. On average, after controlling for engine size, horsepower and model year, imported cars emit 83% less CO, 69% less HC and 68% less NOx than national cars.

The adjustment undertaken in automobiles' characteristics in order to comply with the Proconve regulation can be analyzed by looking at the year dummy coefficients. In general, the adoption of technology to reduce emissions did not start until 1995. We cannot reject the hypothesis of the coefficients on the 1993 and 1994 dummy variables being zero for all three pollutants.

Once manufacturers' efforts to control emissions started in 1995, the timing of reduction adoption was different among fuel types. For gasoline cars, dummy variables for 1995, 1996 and 1997 are statistically significant for almost all pollutants. On the other hand, for ethanol fueled cars, the 1995 dummy variable coefficient is not significant suggesting a later pattern of adjustment undertaken by manufacturers for these models. A clearer picture can be seen if we transform the dummy coefficients in percentage changes for the years in which the dummies were significant, as presented in Table 5.

Table 5
Average Emission Reduction by Year and Fuel Type With Respect to 1992

Year	CO		HC		Nox	
	Gasoline	Ethanol	Gasoline	Ethanol	Gasoline	Ethanol
1995	-24,0%		-24,5%			
1996	-34,2%	-28,6%	-30,9%	-12,3%	-15,7%	-17,1%
1997	-100,0%	-100,0%	-55,4%	-100,0%	-52,6%	-58,4%

Note: percentage reduction in emission by fuel type with respect to 1992 emission level at 95% confidence level, controlling for engine size, horsepower and nationality.

We observe that the compliance pattern was different not only by fuel, but also for the three pollutants. For CO, although the total emissions reduced were equivalent to 100% in the period up to 1997, gasoline cars already had a significant reduction of 24% in 1995 models while ethanol cars reached a 28.6% reduction only in 1996. For HC the control pattern was also primarily undertaken for gasoline models, accounting for a 24.5% reduction in 1995. The control of NOx emissions was quite similar for both gasoline and ethanol models and we cannot reject the hypothesis of an equal percentage reduction between gasoline and ethanol cars.

Another important difference in the compliance trend can be observed by comparing the year dummy coefficients across fuels for the same year. We observe that manufacturers of gasoline cars started their adjustment towards the Proconve standard earlier. For the gasoline regression the 1995 year dummy is significant for most pollutants whereas for the ethanol regression the 1995 year dummy coefficients are not statistically significant.

The decreasing market share of ethanol models may explain their slower adjustment evolution during the period. It reduced incentives for innovations and, consequently, delayed the adoption of pollution control strategies at the very end of the compliance period.

6.2 Compliance schedules and emission trends by car size

Apart from changes in demand between gasoline and ethanol car models, substantial adjustments occurred in the Brazilian automobile market induced by the introduction of the popular car (up to 1000 cc). We analyze the adjustment pattern of emission reduction that occurred in different car size categories.

We break our sample in three groups of cars compatible with the tax regime: popular/small cars (lower than 1,000 cc), medium cars (larger than 1,000 cc but lower than or equal to100 horsepower) and large cars (larger than 100 horsepower) and then regress the log of emissions on year dummies controlling for fuel type, a dummy for imported models and horsepower for each car group.[16] The results are presented in Tables 6, 7 and 8 for CO, HC and NOx respectively.

16 Engine size is omitted since it is not significant once we use tax categories to break our sample.

Table 6
OLS Estimates of Carbon Monoxide (CO) Emissions by Engine Size Group
Dependent Variable: log CO

	Small cars (1,000 cc)	Medium cars >1,000 cc , ″ 100 HP	Large cars > 100 HP
Constant	2.359	1.603	1.328
	(0.603)**	(0.133)**	(0.083)**
Horsepower	-0.022	-0.002	-0.001
	(0.011)	(0.002)	(0.000)**
Gasoline (1=yes)	0.598	0.306	-0.242
	(0.247)*	(0.032)**	(0.060)**
Foreign (1=yes)	-0.921	-0.803	-0.810
	(0.186)**	(0.049)**	(0.042)**
1993 test	-0.088	0.004	-0.002
	(0.158)	(0.040)	(0.090)
1994 test	-0.194	-0.058	-0.080
	(0.207)	(0.048)	(0.099)
1995 test	-0.228	-0.176	-0.188
	(0.150)	(0.042)**	(0.072)**
1996 test	-0.829	-0.455	-0.260
	(0.184)**	(0.051)**	(0.072)**
1997 test	-1.692	-1.591	-0.635
	(0.156)**	(0.053)**	(0.071)**
Observations	142	1483	1655
Adjusted R^2	0.632	0.550	0.439

Notes: White heteroscedasticity consistent standard errors in parentheses. The coefficient for imported ethanol is not available since there are no imported ethanol cars.* Statistically significant at the 5% level.** Statistically significant at the 10% level.

Table 7
OLS Estimates of Hydrocarbon (HC) Emissions by Engine Size Group
Dependent Variable: log HC

	Small cars (1,000 cc)	Medium cars >1,000 cc , ″ 100 HP	Large cars > 100 HP
Constant	-0.516	-0.144	-0.815
	(0.602)	(0.115)	(0.065)**
Horsepower	0.014	-0.003	0.000
	(0.012)	(0.001)*	(0.000)
Gasoline (1=yes)	-0.565	-0.318	-0.567
	(0.214)**	(0.025)**	(0.040)**
Foreign (1=yes)	-0.908	-0.701	-0.455
	(0.186)**	(0.038)**	(0.031)**
1993 test	-0.099	0.021	-0.003
	(0.196)	(0.036)	(0.068)
1994 test	-0.237	0.003	-0.067
	(0.252)	(0.042)	(0.074)
1995 test	-0.161	-0.122	-0.216
	(0.174)	(0.037)**	(0.061)**
1996 test	-0.659	-0.285	-0.242
	(0.188)**	(0.041)**	(0.060)**
1997 test	-1.500	-1.196	-0.443
	(0.172)**	(0.040)**	(0.059)**
Observations	142	1483	1655
Adjusted R^2	0.565	0.633	0.394

Notes: White heteroscedasticity consistent standard errors in parentheses. The coefficient for imported ethanol is not available since there are no imported ethanol cars.* Statistically significant at the 5% level.** Statistically significant at the 10% level.

Table 8
OLS Estimates of Oxide (NOx) Emissions by Engine Size Group
Dependent Variable: log NOx

	Small cars (1,000 cc)	Medium cars >1,000 cc , ″ 100 HP	Large cars > 100 HP
Constant	-1.442	-1.056	-0.310
	(0.492)**	(0.157)**	(0.080)**
Horsepower	0.003	0.005	-0.003
	(0.010)	(0.002)**	(0.000)**
Gasoline (1=yes)	1.027	0.152	-0.052
	(0.124)**	(0.037)**	(0.047)
Foreign (1=yes)	-0.142	-0.546	-0.634
	(0.179)	(0.051)**	(0.037)**
1993 test	-0.091	-0.061	-0.045
	(0.181)	(0.067)	(0.082)
1994 test	-0.178	0.002	0.059
	(0.235)	(0.072)	(0.086)
1995 test	-0.113	-0.142	0.004
	(0.154)	(0.063)*	(0.073)
1996 test	-0.355	-0.265	-0.027
	(0.158)*	(0.063)**	(0.072)
1997 test	-1.250	-0.993	-0.541
	(0.183)**	(0.068)**	(0.074)**
Observations	142	1483	1655
Adjusted R^2	0.419	0.288	0.377

Notes: White heteroscedasticity consistent standard errors in parentheses. The coefficient for imported ethanol is not available since there are no imported ethanol cars.* Statistically significant at the 5% level.** Statistically significant at the 10% level.

Most estimated equations have a satisfactory fitting with an R^2 varying between 0.28 and 0.63. A higher proportion of the variance in the log of emissions is explained by the small and medium car regressions with the exception of the NOx pollutant where all three car segments have similar adjusted-R^2

Since we divided the sample in tax bracket categories, we also introduce a dummy variable for fuel to control for different fuel technology used in gasoline and ethanol cars. This dummy is statistically significant in almost all equations, but the sign of the coefficient differs among pollutants. While gasoline cars emit, on average, more HC and NOx, ethanol car models are cleaner with respect to HC emissions. The greatest difference emerge on small cars for which the emission of gasoline models is 89% higher for CO and 179% higher for NOX, after controlling for other characteristics.

Additionally to the fuel dummy variable, a dummy that equals one for foreign car models is also used as in the previous analysis. The dummy for foreign cars is also significant for all car sizes and pollutants except for small cars NOx emissions. For all car sizes and pollutants foreign cars pollute, on average, less than national cars. This difference is greater for small cars, where foreign small cars generate 60% less emissions of CO and HC, and 13% less emissions of NOx. These results suggest that there have occurred environmental gains with the proliferation of imported cars as occurred in the United States with the entrance of Japanese vehicles. (Kahn, 1996)

Once we break our sample into car sizes, horsepower is only significant for explaining emission levels of CO and NOx for large cars, with the same negative sign as previously found. For small cars with 1000cc there is a lack of variation in horsepower and the lack of significance in this coefficient is not surprising. For the emission of HC, horsepower is not a significant explanatory variable at the 95% confidence level.

Controlling for horsepower, nationality and fuel type we can undertake the analysis of the compliance pattern across car sizes by looking at the coefficients of the year dummy variables. For all three categories of cars analyzed, there were no substantial reduction of average emissions prior to 1995. Statistically, for all pollutants and car categories, we could not reject the null hypothesis of zero reduction in average emissions between 1992 and 1994. These results indicate that although manufacturers had a five year period for implementing cleaner technological devices, they waited until 1995 to initiate the adjustment process.

In Table 9 we present the transformed coefficients for the statistically significant year dummy variables. The coefficients can be interpreted as average percentage reductions, with respect to the 1992 emission level, once we control for horsepower, fuel type and nationality.

Table 9
Average Emission Reduction by Year and Size With Respect to 1992

Year	CO			HC			NOx		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
1995		-16.1%	-17.1%		-11.5%	-19.4%			
1996	-56.3%	-36.6%	-22.9%	-48.3%	-24.8%	-21.5%		-23.3%	
1997	-81.6%	-79.6%	-47.0%	-77.7%	-69.8%	-35.8%	-71.3%	-62.9%	-41.8%

Note: percentage reduction in emission by fuel type with respect to 1992 at 95% confidence level, controlling for horsepower, fuel type and nationality.

We observe that small cars had a slowest reduction pattern for all three pollutants analyzed. While medium and large cars had already reduced, on average, 11% to 19% CO and HC emissions in 1995, no significant control of emissions for popular cars were undertaken up to this year.

At the same time, small cars were among the dirtiest models in 1992, which implied that a larger percentage of emission reduction had to be undertaken for this type of car models. This adjustment occurred later in 1996 when there was a 56% reduction in CO emissions and a 48% reduction of HC emissions with respect to 1992. In terms of the final average emission reduction, the largest reduction in emissions was undertaken in popular car models accounting for 82% for CO, 78% for HC and 71% for NOx.

Manufacturers started the technology adjustment in medium and large cars earlier. By 1995 technology innovation and the introduction of electronic fuel injections reduced emissions by 16% for CO and 12% for HC. For large cars, the reduction of CO from 1992 to 1995 was, on average, 17% for CO, 19% for HC with no significant reductions for NOx.

In contrast with other countries, large cars in Brazil were among the cleanest models in 1992. This was probably due to the tax subsidy offered for electronic fuel injection adoption. Since then, average emission reductions were much lower than small and medium cars. The average total reduction for large cars from 1992 to 1997 was 47% for CO, 36% for HC and 41% for NOx. Moreover, since 1992 most of this adjustment was undertaken with the introduction of more technologically advanced injection and catalytic converters.

These differences in compliance schedules may be explained by the fact that, in order to attract consumers to lower power models, the industry tried to keep prices down by not incorporating expensive emission control technologies which would have made "popular" and medium cars cleaner though also more expensive. Thus the market strategy for manufacturers was to pursue slower compliance schedules for such models in order to increase market share.

These adjustment patterns are expected since the automobile industry faces increasing marginal production costs of emission control technologies. Berry, Kortum and Pakes (1996) used a hedonic cost function approach to show that production costs in the US car industry moved upwards in the period 1972/82 due to tightened emission standards. The authors indicate that catalytic converters, usually the first control device introduced in the US as well as in Brazil, did not have significant impacts on costs whereas advanced technologies such as electronic fuel injection increased costs significantly.

This pattern of compliance is also closely related to the existent market power in different car segments of the Brazilian automobile industry. Fiuza (2000) finds that markups for popular cars were higher than markups for larger cars. This may help to explain why manufacturers postponed the adjustment in popular car models which implied introducing electronic injection devices and catalytic converters and passing this cost to prices.[17]

Nevertheless, it is hard to separate the effect of electronic injection and other clean characteristics on prices and car sales due to the simultaneous effect on emission reduction and quality increase in the automobile.[18]

7 Concluding remarks

The Brazilian automobile industry faced its first environmental regulation with the introduction of the Proconve in 1988. It obliged all car models sold to comply, within a ten-year period, with a maximum emission level for several pollutants. This paper uses emission and characteristics data from the São Paulo Environmental Agency (Cetesb) to analyze the pattern of compliance that occurred during the second phase of the Proconve: the 1992-1997 period.

17 See Ferraz, Fiuza and Seroa da Motta (2000) for an analysis of the impact of the environmental regulation in the automobile oligopolistic market.

18 Fonseca (1997) estimates a quality index for the Brazilian automobile using a hedonic price analysis. He finds that the trend of price increases from 1980 to 1994 was highly associated to increases in car quality, including emission control devices during the later years.

By estimating semi-log regressions of emissions as a function of several car characteristics and model year, we are able to examine the pattern of pollution reductions adopted by manufacturers for different kinds of fuel, car size categories and pollutants. The estimated results show that average emissions from cars produced in Brazil decreased substantially with the imposition of the Proconve regulation. On average, emissions from gasoline fueled car models decreased by 93%, 88% and 89%, respectively for CO, HC and NOx. Average emissions from ethanol cars also decreased in similar scale.

Nonetheless, the results also indicate that the compliance trend adopted by manufacturers was not homogeneous. While manufacturers reduced pollution emissions of gasoline and large car models first, ethanol and small (popular) vehicles pollution control lagged behind.

Another important finding obtained from our estimated model is that, even after the adjustment process, foreign cars pollute, on average, substantially less than Brazilian car models. Therefore, the increasing foreign investment for production of cars in local plants may have had an important environmental effect by decreasing average emission of new cars sold. Additionally, new technology have probably created spillovers by making new technology available to national manufacturers.

Despite the fact that there was a significant difference in the compliance trend between car types, we conclude that on average, all manufacturers waited until the last three years of the compliance period to introduce significant technological changes that reduced pollution emissions. This pattern of compliance was generated by the long period allowed for adjustment and the lack of economic incentives for early compliers. Moreover, when such an incentive was implemented, such as the tax exception of 5% given to large car manufacturers which adopted fuel injection, manufacturers readily adopted emission reduction technology devices.

This compliance pattern is not peculiar to the Brazilian case. In the United States, Kahn (1996) shows that a similar pattern of emission control occurred after the imposition of the clean air act. US automobile manufacturers allowed a significant period of time for emission reduction, also waited until the very end of the binding period.

Clearly, such a compliance schedule is not efficient. Once technology is available at feasible costs with marginal costs of pollution abatement that are at least equal to social marginal benefit, it would be efficient for society if manufacturers promptly adopted such technology.

One way to implement such an adoption would be to use economic incentives for pollution control. This paper indicates that the Brazilian automobile market responds strongly to economic incentives. The technological adjustment undertaken by manufacturers was closely related to economic incentives that occurred as a consequence of a diverse set of government policies. Several economic factors, such as the gradual decrease in sales of ethanol cars, the appearance of the "carro popular" in 1992 and the trade liberalization process affected the Brazilian automobile market during the nineties and therefore, influenced the timing of the adoption of pollution control technology.

Nevertheless, even tough the Proconve environmental regulation generated substantial technological improvements, no further incentives for pollution control were created after 1997 Without an additional encouragement, manufacturers lack motivation for undertaking investment in developing cleaner technology for vehicles. This incentive is needed in a context of increasing urbanization, rising car use, growing car fleet and poor public transportation systems.

Although several local solutions are being implemented for specific situations such as the *Rodizio* (car use restrictions) in the São Paulo metropolitan area, greater attention has to be placed on the importance of reducing national vehicle pollution emissions in metropolitan regions.

Additional policies that could create incentives for selling cleaner automobiles and driving fewer miles should be combined with the inspections of currently circulating vehicles and the scrappage of older and dirtier car models. At the same time, a coherent policy for controlling urban air pollution also has to account for alternative public transportation systems in order to reduce individual vehicle usage. Only with such comprehensive approach will the strategy for car pollution regulation bring about welfare gains.

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