# Automobile Pollution Control in Brazil

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**Abstract**

Air pollution concentrations have been rapidly increasing in the major urban areas of Brazil caused mainly by the increasing use of vehicles. Policies to control car emissions in Brazil have relied basically on mandatory emission standards and subsidies for specific cleaner technology resulting in substantial decrease of car emission rates. Nevertheless, taxes on car sales, differentiated by vehicles' size and fuel, have also influenced car emission patterns. This paper analyses the compliance trend of the Brazilian fleet with environmental standards between 1992 and 1997. We find that larger automobiles had the fastest compliance schedule while popular models adjusted very slowly. Also gasoline-fuelled models had a faster adjustment pattern than ethanol cars. Additionally, we analyse the current relationship between pollution emissions and car characteristics in order to orient policy formulation. We find a positive relationship between emissions rates and horse power, concluding that although the current value-added sale car tax is not environmental harmful, a tax differentiating clean from dirty models, within each tax bracket, could create substantial incentives for emission control in the future.

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# Introduction

Urban air pollution is a serious environmental problem in developed as well as in most developing countries. In the case of Brazil, air pollution concentrations have been rapidly increasing in the major urban areas over the last decades. As elsewhere, this expansion has been caused mainly by the increasing use of vehicles. Today, emissions from vehicles are the major source of air pollution in Brazil's largest cities. In 1997 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% particulate matter (PM)[1].

Costs associated with high air pollution concentrations in large cities are known to be important. Human health costs predominate, and range from eye irritations to respiratory problems and increasing cancer rates, all of which induce direct and indirect costs to society[2]. Seroa da Motta and Fernandes Mendes (1995) estimate a reduction of 7% in the mortality rate from respiratory diseases 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 alone the aggregate social emission costs. Consequently, their preferences will usually not consider fuel and car cleanliness. In the presence of this negative externality, environmental regulation is required.

The economic literature is replete with identifying market-based instruments (MBIs), such as taxes and tradable permits, as more efficient ways to achieve environmental goals than emission and technological standards, commonly referred to as command-and-control mechanisms (C&C). C&C instruments are based on standards which all users are forced to comply with in order to reach the minimum desirable level of pollution. In the case of car emissions, all automobiles and fuels are sold according to certain mandatory technological or emission standard targets. If enforcement is strong, non-compliance would mean no sale and users would either comply or leave the market. There are no trade-off schemes among producers or consumers to allow for cost minimisation strategies. Such lack of flexibility impedes cost-effectiveness gains.

Alternatively, by introducing an environmental tax equivalent to the social marginal cost of pollution emission (Pigovian tax), regulators force consumers to internalise their contribution to the aggregate social costs. In doing so, society reaches the optimal level of pollution when the marginal cost of pollution damages equals the marginal cost of pollution control. However, such optimal taxation requires the measurement of emissions from every single emission source and the determination of the marginal damage cost of one unit of emission.

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[1] See CETESB (1998). Also in São Paulo, according to CETESB (1998), the air quality is considered to be below the human health minimum standard at least 25% of the days in a year.
[2] See Watkins (1991) and Maddison et al. (1996) for further analysis of health effects associated with vehicle source air pollution.

If we were able to measure emissions by individual cars, the first best incentive option for car emission control would be the imposition of a Pigovian tax on each source according to its marginal contribution to air pollution damages. This would allow flexibility for car owners in the choice of emission reduction strategies. However, such first best approaches can incur high administrative cost. As put by Innes (1996), even if tamper-resistant emission-measurement from tailpipes were available at reasonable costs, such devices do not detect important non-tailpipe pollution and, therefore, high costly reliable periodic car monitoring would be required. Consequently, the application of car emission control policies would have to reckon on regimes which do not require direct emission monitoring.

When emission output measurements are difficult, the economic literature on MBIs proposes instead that regulators may apply first best taxes on the use of inputs and products which are related to emissions. For car emissions, fuel and automobile taxes are good candidates for this option. Fullerton and West (1999 - hereafter FW), have derived a set of fuel and car optimal taxes which are able to mimic, at least in theory, the unavailable tax on emissions. In order to derive a closed form solution, FW consider emissions per gallon (EPG) and miles per gallon (MPG) only to depend on $s_i$, the size of the car. Under these specific technological conditions, FW propose a closed form solution for a fuel tax $(t_g)$ differing according to characteristics of the vehicle at the pump.

The owner of car model *i*, would pay a tax given by

$$t_{gi} = \mu EPM(s_i)MPG(s_i)$$

where $\mu$, represents the marginal social cost of a unit of emissions and EPG and MPG represent car features. More generally, we could specify such a tax to be a function of other car characteristics which are likely to affect EPG and MPG, as well as emission features of different fuel types.

Admitting regulators know the mileage consumption and useful life of each car model *i* owned by consumer *j*, an equivalent car sale tax would consist of the present value of the above fuel tax. This car tax could be, instead, applied periodically for licensing purposes, and its value would be set by monitored mileage at that period.

Both fuel and car taxes would make consumers perceive the emission-increasing cost of extra mileage consumption and recognise the emission-reducing benefits of fuel cleanness and economy as well as car pollution abatement devices.

Note that under this approach regulators must know the marginal social cost of a unit of emissions ($\mu$). Moreover, this parameter will be location-specific since marginal damages are dependant on total pollution charges and the environment assimilative capacity which, in turn, varies according to atmospheric variables (e.g., wind speed, temperature, humidity, etc).

Suppose, however, that regulators know $\mu$ and location-specific taxes can be applied. Although the fuel tax is simpler than the equivalent car tax, it would still require car features to be identifiable at the gas station. Again such an approach is likely to generate high administrative costs in order to be feasible and reliable. Therefore, if we cannot mimic the first best solution with alternative taxation schemes, we would have to rely on second best market instruments. The ideal second best mechanism should create price incentives for

consumers to drive fewer miles and, at the same time, buy cleaner cars. While the former decision is related to fuel use, the latter works through car price differentiation[3].
A car tax based on the estimation of a vehicle's annual emission is proposed by Eskeland (1994) and Sevigny (1998). Emission rates per mile would be estimated based on car characteristics, and miles travelled could be measured by the change in the vehicle's odometer in a given year[4]. What makes this proposal different from the first best alternative proposed by FW is the lack of knowledge on each specific car's EPM. While FW's model assumes that it is possible to estimate individual EPM for all car models in order to charge an emission gas tax at the fuel pump, Sevigny (1998) only expects to be able to derive average EPM figures. Again, implementation may prove to be costly for the case of odometer measurement procedures.

An alternative constrained optimal regulation is proposed by Innes (1996). A combination of taxes on gasoline and automobiles could be combined with a government fuel content standard. The fuel tax would be independent of individual automobiles, but the car tax would depend on auto characteristics (eg, power, size, style), fuel economy and abatement features. Since mileage demand is highly correlated with automobile features, the automobile tax would also affect miles driven. Moreover, additional incentives could be created. In a dynamic setting, a car sale tax could be partially returned to consumers as incentive for scrapping older models according to the abbreviation of the car's useful life[5].

For the previous mechanism, a subsidy for pollution control equipment is relatively simple to define since control equipment such as catalytic converters and filters are directly observable. The same applies for fuel, insofar as that emissions will rise more or less proportionately with fuel consumption for a given vehicle and given driving conditions[6]. On the other hand, a tax on car characteristics requires a periodic identification of the relationship between car characteristics and emissions.

In general, market based instruments are difficult to implement and regulators wishing to apply them would have to combine tax schemes with technological and emission standards. This approach does not maximise social welfare by setting optimal levels of pollution. Rather, the aim is to use pricing mechanisms to increase cost-effectiveness in achieving a certain standard compliance regarded as desirable[7]. That is, once environmental goals are defined, economic instruments can reduce the social costs of achieving them. The rationale is rather simple. Since users face different marginal control cost schedules, pollution taxes varying directly with users' pollution levels will make users adopt control levels up to the point where pollution control costs are equal, at the margin, to non-compliance tax costs. Taxes are set at certain level which will make the maximised individual decisions, in aggregate, to meet the desirable standards. Society will first start to control from the least-cost users which will reduce total control cost. In this case, individual emission standards are

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[3] See Johnstone and Karousakis (1998) for a review.
[4] This tax would take the form of Annual tax =, $(aEPM_1 + bEPM_2 + cEPM_3) * VMT$ where EPM is the emission per mile, VMT is the vehicle mile traveled and a, b, c are tax rates set to induce the desired level of abatement for each pollutant.
[5] Road fees, varying with air pollution concentration levels and car's characteristics, are also regarded as possible second best options, although they may induce longer travel distances to avoid charges.
[6] See Seroa da Motta and Mendes (1996) for an analysis of fuel taxation in Brazil.
[7] Desirable here may mean either one standard politically acceptable or targeted at one specific damage. In the case of urban pollution, human health damages are usually targeted.

dropped out and regulators become only concerned with ambient standards which reflect total emissions.

Instead of setting prices, regulators may distribute pollution permits to users, as a share of the desired total emission targets and allow these permits to be traded among users. This mechanism creates incentives for achieving the same marginal cost equalising outcome given the competitive structure of the prices emerging from the permit market transactions.

Apart from cost-effectiveness benefits, such economic instruments can generate revenue. In the case of pricing mechanisms, note that users with non-compliance will face the respective tax costs and thereby generate a tax revenue. In the case of tradable permits, they can be distributed through auctioning mechanisms[8].

Car emission control policy in Brazil is basically defined on mandatory emission standards. Since 1988 the Brazilian governmental authorities have implemented a regulatory mechanism called The Vehicle Air Pollution Control Programme (PROCONVE), establishing maximum pollution emission standards (in grams per kilometer) for new vehicles entering the market. The program has been very successful in reducing emissions per kilometer for new car models. Nevertheless, as with any command and control approach, it is inflexible and increases the costs of reducing pollution.

This paper analyses the evolution of average emissions in the Brazilian fleet between 1992 and 1997 (the final compliance date). Together with environmental policy, car tax structures have been differentiated by car characteristics such as size and fuel use, in order to accommodate sectoral policy aims. Therefore, government initiatives have affected the car market and consequently the emission pattern of new automobiles. We try to relate these sectoral policies with the average emission compliance trends comparing the average emission changes across car sizes and fuel types. Additionally, we analyse the present relationship between pollution emissions and car characteristics in order to orient current policy formulation. Our analysis is based on emission data recorded from laboratory tests undertaken by the São Paulo Environmental Agency (CETESB) which electronically measures emissions of HC, CO and NOx for each car model along with the model's characteristics.

The rest of this paper is structured as follows: the next section presents the Brazilian regulatory framework for car pollution control and the car tax structure. This is followed by a description of our database and model characteristics. Section 4 presents the econometric results; concluding remarks and policy recommendations are discussed in the final section.

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[8] Cost-effectiveness of permits does not depend on permit auctioning. Freely distributed permits have different equity effects, although they are equally cost-effective if transactions costs are assumed not constrained.

# Environmental Regulation, Fiscal Policies and the Brazilian Car Market

Recently, three different policies have shaped the size, the structure and the composition of the car fleet in Brazil: the ethanol programme, the sale car tax changes and the environmental regulation. Moreover, all of them had substantially affected the pattern of pollution emissions[9].

**The Vehicle Air Pollution Control programme (PROCONVE)**

The introduction of emission control devices in Brazilian vehicles was promoted by the 1986 protocol signed between the automotive industry and the government - the Vehicle Air Pollution Control Programme (PROCONVE) - which was later turned into a law. PROCONVE was, in fact, the first attempt in Brazil to control pollution emissions from automobiles directly. It defined targets for emission controls in new cars for the period 1988-97, according to the timetable presented in Table 1. It is important to note that these targets were as ambitious as those applied in some OECD countries.

**Table 1 Emission standards for new cars in Brazil (g/km)**

| Year | Carbon Monoxide (CO) | Hydrocarbons (HC) | Nitrogen Oxide (NOx) |
|---|---|---|---|
| 1988 | 24.0 | 2.1 | 2.0 |
| 1992 | 12.0 | 1.2 | 1.4 |
| 1997 | 2.0 | 0.3 | 0.6 |

Source: Brazilian National Environmental Code (CONAMA) resolution No. 18, 1986.

The Protocol was successfully implemented and average emission levels of new cars decreased considerably. Hydrocarbon emissions, for example, decreased by approximately 92% for gasoline and 84% for ethanol cars, between 1988 and 1997. In sum, the PROCONVE mandatory emission standards were an effective command-and-control mechanism for reducing pollutant emission levels from vehicle sources. The adaptation was attained through the use of internationally available technology, mainly catalytic converters and the increased adoption of fuel injection.

**Car tax structures**

Car taxation in Brazil is recognised as very high, varying from 23 to 33% of average car price. Apart from two minor social contributions, it is comprised primarily of two parts, a state circulation value added tax (ICMS) and a federal industrial value added tax (IPI). The latter is higher and is progressive with a vehicle's power (HP). The differentials among tax classes have been changing in the last decade in order to accommodate sectoral policy objectives, such as, the promotion of ethanol fueled and popular cars (1,000 cc).

[9] Trade liberalisation also had an important effect on the Brazilian car market. Nevertheless, due to the lack of data, it is not directly considered in our analysis. See De Negri (1998).

Tax rate differential by fuel type cars

The first major factor contributing to the reduction of vehicle emissions in Brazil occurred indirectly as a response to the first oil crisis in the 1970s with the addition of ethanol to gasoline through the Brazilian National Alcohol Programme (PROALCOOL). Its main environmental benefit was the complete removal of lead from gasoline. After the second oil crisis, Brazil initiated a further phase of PROALCOOL, aimed at the sale of pure ethanol-fueled cars. Pure ethanol-fueled vehicles were, at that time, relatively cleaner in terms of certain pollutants than gasoline-fueled vehicles. Nevertheless, they require a higher volumetric fuel consumption per mile travelled[10].

To promote the sale of pure ethanol cars, the government relied on very aggressive fiscal and credit demand and supply-side incentives. Ethanol fuel prices were set favourably relative to gasoline (reducing its relative price) and ethanol cars were also sold with lower sale tax rates and better financing schemes.

In the late 1980s, the continuous decline in international oil prices and the severe public 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 at the beginning of the 1990s. This process suggests that the tax rate differential was not sufficient to avoid the dramatic drop in ethanol car sales. Relative fuel prices and availability, which directly affect car use levels, played a far more important role for consumer's choice[11].

Finally in 1991, after some periods of fluctuation in the ethanol content of the gasohol mixture, a law was passed stating that the gasohol mixture had to be kept at the constant 22% level[12], changed to 24% later on. Gasohol then became the main source of ethanol demand, particularly in recent years when fuel consumption peaked after the macroeconomic stabilisation. The stability of the mixture used for automobile fuel allowed the automotive industry to accelerate the introduction of technological innovations, particularly those for car emission control.

Tax rate differential by engine size

Car taxation is also used in Brazil to achieve sectoral policy objectives. Value added taxes were reduced for cars with lower horsepower (cheaper automobiles) in order to promote production and employment. This differentiation has had significant environmental consequences.

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 2. This differentiation was accentuated with the introduction of the 'carro popular' (less or equal than 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 in the car

[10] Today around 15-20% depending of the model.
[11] Note that theses findings also corroborate the theoretical issues discussed on Section 1 which emphasises the need to combine car and fuel price taxation.
[12] The law accepts a variance of 2%.

market[13]. It was further increased to 8% in 1995 and to 13% in 1997. As can be seen, these tax reductions are more substantial than those offered for ethanol cars.

**Table 2 Evolution of the IPI for automobiles in Brazil (%)**

| 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 |
|---|---|---|---|---|---|
| 1986 | - | 100 | 92 | 107 | 100 |
| 1987 | - | 45 | 40 | 50 | 45 |
| 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.

In order to subsidise environmental compliance to the 1992 PROCONVE targets, government offered a reduction of 5% on the industrial value added tax levels for some large cars (between 100 and 127 HP) which adopted fuel injection devices from 1992 onwards. This incentive worked well and from 1992 onwards all models over 100 HP had already adopted fuel injection devices. It is important to note that the electronic injection subsidy worked equivalently to a sale tax on dirtiest large cars which would have not adopt this emission control device.

[13] In this case, the state value-added tax (ICMS) was also differentiated for 'popular cars' for certain periods.
[14] Since we are interested in local pollution, we chosen not to use data on $CO_2$ emissions which are very controversial.

# Car Emissions and Characteristics

Emissions and characteristics data have been used to analyse pollution regulations and the possibility of implementing an environmental vehicle characteristic tax. White (1982) and Kahn (1996) use cross-section data to investigate the evolution of manufacturers' compliance with pollution regulation in the United States. Under a different approach, Johnstone and Karousakis (1998) use emissions and characteristics to study the possibility of implementing a vehicle characteristic tax. We build upon these previous studies in order to analyse both the evolution of compliance to the new regulation and the current relationship between characteristics and emissions for the Brazilian fleet.

We assume that automobile *i* has a production function for pollution emissions represented by:

$$E_i = f(MY_i, C_i) \qquad (1)$$

where *MY* is model year and *C* is a vector of characteristics which includes, among others, engine size, horse power, electronic injection, fuel type and catalytic converter.

Based on this model, our econometric exercise analyses the evolution of the emission compliance pattern in the car industry in Brazil for the period 1992-97. The emission trend is analysed across fuel types and engine size categories. Additionally, a specific cross-section regression is undertaken for 1997 in order to analyse the relationship between emissions and characteristics.

Our data was obtained from laboratory tests undertaken by the São Paulo Environmental Agency (CETESB) which recorded the emissions of HC, CO and NOx for each car model along with the model's characteristics[14]. Since CETESB only tests auto engine and emissions by family type, the same emission test is usually used for cars with the same engine, but with different weight, size and maximum speed. Consequently, we can only use one of the observations for statistical analysis purposes. Furthermore, since different weights are associated with the same emission rate, we cannot use such a variable for our analysis.

Other characteristics like cylinders and transmission are not used since they are almost uniform in Brazil (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, fuel injection type/carburetor and the year of the test. Nevertheless, due to the high correlation between engine size and horsepower, which caused significant multicolinearity in our model, we opted to include only horsepower in the estimation[15].

Additionally, we merged the CETESB database with our price and quantity database obtained from the Quatro Rodas magazine and Auto Part Manufacturer's National Syndicate (Sindipeças) in order to ensure that only car models with positive sales were included in the

[15] The results do not change substantially when we include engine size instead of horse power. Nevertheless, due to its greater variability, the model has a better fit with horse power.

analysis. Since many different car models had the same emission test, we had to clean the database until there was only one observation from each family of cars. On this basis we ended up with 444 observations from 1992 to 1997.

The emission compliance process is analysed by fuel type (gasoline and ethanol) and car size (small, medium and large). Controlling for horsepower and rpm (since CETESB tests are undertaken in different rpm), we include dummies for test years and obtain the percentage change in emissions through time.

The analysis is undertaken for the three pollutants CO, HC and NOx using a simplified version of equation (1) given by:

$$\log e_i = \alpha + \beta_1 hp_i + \beta_2 rpm_i + \sum_{j=1}^{4} \gamma_j dyear_{ij} + \varepsilon_i \qquad (2)$$

where *hp* is horse power, *rpm* is rotations per minute and *dyear* are dummies taking the value 1 if the car was tested in that year and zero otherwise and $\varepsilon$ is the error term. The dummy year for the test is used as proxy for the model year.

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 $e^{\gamma} - 1$. The results are discussed based on the transformed coefficients. It is also important to point out that, since model year dummies have 1992 as the base year, all year dummy coefficients represent variations against 1992.

The second regression equation aims at analysing the current relationship between emissions and characteristics in the Brazilian fleet. We use 1997 test data and a model similar to Johnstone and Kourasakis (1998). Regressing emissions on vehicle characteristics and controlling for rpm, we are able to distinguish the different effects of horse power, single-point or multi-point fuel injection and fuel type on emissions of CO, HC and NOx. The econometric model estimated is given by:

$$\log e_i = \alpha + \beta_1 hp_i + \beta_2 rpm_i + \beta_3 singlefuel_i + \beta_4 gas_i + \varepsilon_i \qquad (3)$$

where *hp* is horse power, *rpm* is rotations per minute, *singlefuel* is a dummy variable taking the value of 0 if the car has multi-point and 1 if it has single-point fuel injection and *gas* is a dummy variable taking the value of 1 if the car is gas-fueled and 0 if it is ethanol-fueled. Due to the presence of heteroscedasticity in some regressions, White-consistent standard errors are used.

# Econometric Results

**The evolution of emissions compliance, 1992-1997**

Due to the small number and unequal distribution of observations across time, it is not possible to undertake a cross-section analysis for each pollutant by each model year. Moreover, car models vary across years, hence it is also not possible to use panel-data estimation techniques. We opted for pooling all observations controlling for variables that influence emissions such as the horse power, rotations per minute and the presence of fuel injection and adding dummy variables for each test year. Following Kahn (1996) we use a cross-section regression to analyse the effects of pollution regulation in Brazil through the period 1992-97.

Compliance schedules and emission trends by fuel type

Divergence in emission levels among fuel-type cars can be observed in Table 3. Gasoline cars adapted to the regulation first while ethanol cars had a significant adaptation lag. As mentioned above, this divergence pattern could be explained by the lost of market share of ethanol cars and consequently, the decrease in the R&D invested in cleaner technologies.

As shown in Table 3, by 1992 the HC emission levels from ethanol cars exceeded those from gasohol cars. This trend may be explained by the fact that there were no longer any special sale opportunities for ethanol cars and, consequently, technological efforts were concentrated on gasohol models.

**Table 3: Evolution of average emission levels of new passenger vehicles in Brazil by fuel type (g/km)**

| | Gasohol | | | | | | Ethanol | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | | | Standard Deviation | | | Mean | | | Standard Deviation | | |
| Year | CO | HC | NOX | CO | HC | NOX | CO | HC | NOX | CO | HC | NOX |
| 1992 | 5,88 | 0,49 | 0,75 | 1,82 | 0,19 | 0,30 | 4,04 | 0,61 | 0,61 | 1,34 | 0,15 | 0,27 |
| 1993 | 5,57 | 0,47 | 0,68 | 2,17 | 0,21 | 0,32 | 4,34 | 0,62 | 0,62 | 1,64 | 0,16 | 0,30 |
| 1994 | 5,02 | 0,45 | 0,65 | 2,43 | 0,24 | 0,32 | 4,02 | 0,63 | 0,63 | 1,48 | 0,15 | 0,27 |
| 1995 | 4,74 | 0,41 | 0,64 | 2,50 | 0,25 | 0,27 | 3,82 | 0,57 | 0,57 | 1,68 | 0,16 | 0,22 |
| 1996 | 3,80 | 0,35 | 0,55 | 2,59 | 0,24 | 0,28 | 3,59 | 0,55 | 0,56 | 1,79 | 0,19 | 0,25 |
| 1997 | 1,06 | 0,13 | 0,32 | 0,84 | 0,05 | 0,14 | 0,66 | 0,19 | 0,19 | 1,18 | 0,03 | 0,06 |

Note: Simple average excluding station wagons, pick ups and sport utility vehicles. CO=Carbon Monoxide; HC = Hydrocarbons; NOx = Nitrogen Oxide
Source: Authors' calculations

In order to analyse these compliance schedules, we estimate separate regressions for each fuel type and for the three pollutants. Controlling for horsepower and rpm, we analyse the evolution of average emissions after 1992. The regression results are presented in Table 4.

**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 | 2.973* | -1.087 | -0.665* | -2.367* | -0.891* | -3.943* |
| | (0.355) | (0.657) | (0.316) | (0.690) | (0.369) | (0.710) |
| Horse power | -0.012* | -0.004 | -0.009* | -0.009* | -0.003* | 0.007** |
| | (0.001) | (0.003) | (0.001) | (0.002) | (0.001) | (0.002) |
| RPM | -0.00005 | 0.0005* | 0.0001** | 0.0005* | 0.0001** | 0.0004* |
| | (0.00007) | (0.0001) | (0.00006) | (0.0001) | (0.00007) | (0.0001) |
| 1993 test | -0.055 | 0.047 | -0.026 | -0.0007 | -0.074 | -0.034 |
| | (0.105) | (0.123) | (0.087) | (0.084) | (0.122) | (0.133) |
| 1994 test | -0.168 | 0.004 | -0.080 | 0.011 | -0.099 | -0.046 |
| | (0.115) | (0.127) | (0.099) | (0.086) | (0.123) | (0.136) |
| 1995 test | -0.312* | -0.107 | -0.240* | -0.062 | -0.115 | -0.083 |
| | (0.109) | (0.117) | (0.094) | (0.080) | (0.116) | (0.123) |
| 1996 test | -0.633* | -0.248** | -0.431* | -0.133 | -0.324* | -0.146 |
| | (0.121) | (0.138) | (0.097) | (0.094) | (0.113) | (0.125) |
| 1997 test | -1.623* | -1.686* | -1.194* | -1.123* | -0.773* | -1.002* |
| | (0.132) | (0.162) | (0.107) | (0.105) | (0.126) | (0.210) |
| Number of observations | 298 | 146 | 298 | 146 | 298 | 146 |
| Adjusted $R^2$ | 0.47 | 0.35 | 0.42 | 0.42 | 0.17 | 0.24 |

Notes: White heteroscedasticity consistent standard errors and covariance. Standard errors on parentheses. Small cars correspond to 1,000cc. Medium cars are higher than 1,000cc, but lower than 100hp. Large cars are higher than 100hp.
* Statistically significant at the 5% level.
** Statistically significant at the 10% level.

Except for NOx, the characteristics and test year dummies perform quite well in explaining the variance of pollutant emissions. Moreover, the results are consistent with our hypothesis. For gasoline cars, dummy variables for 1995, 1996 and 1997 are statistically significant for almost all pollutants. This implies that since 1995 gasoline cars adopted cleaner technologies which decreased average emissions in a statistically significant manner. On the other hand, ethanol cars only adopted significant reductions much later in order to comply with the 1997 standards. This can be observed by the fact that, except for CO in 1996, the only statistical significant dummy for ethanol is for 1997. We can conclude that for all other previous years, average emissions were not statistically reduced with respect to 1992 emissions.

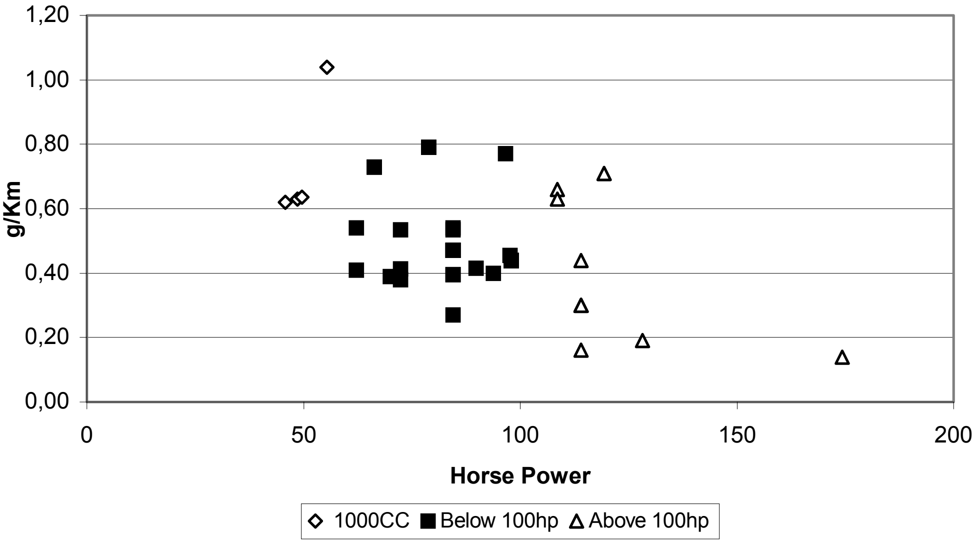
Gasoline cars started their technological adjustment in 1993, while there was only a slight decrease in emissions (or increase depending on the pollutant analysed) from ethanol cars. Although in 1993 and 1994 adjustments in the emission rates of gasoline cars were not significant, in 1995 the decrease in average emissions reached 26.8% for CO, 21.3% for HC and 10.9% for NOx, whereas the highest reduction for ethanol cars only represented 10.2% for CO in the same year.

Although total emission reductions for gasoline and ethanol vehicles for 1992 to 1997 are quite comparable, reductions from 1996 to 1997 were much higher for ethanol while gasoline cars undertook the adjustment in a more gradual fashion. This slower adjustment of ethanol vehicles can be explained by their decreasing market share during the period which reduced incentives for innovations. Due to the decline in the market share of ethanol-fueled vehicles, we could expect ethanol cars to have adopted pollution control strategies at the very end of the compliance period, while gasoline cars, which were gaining market share, probably adopted cleaner technologies earlier.

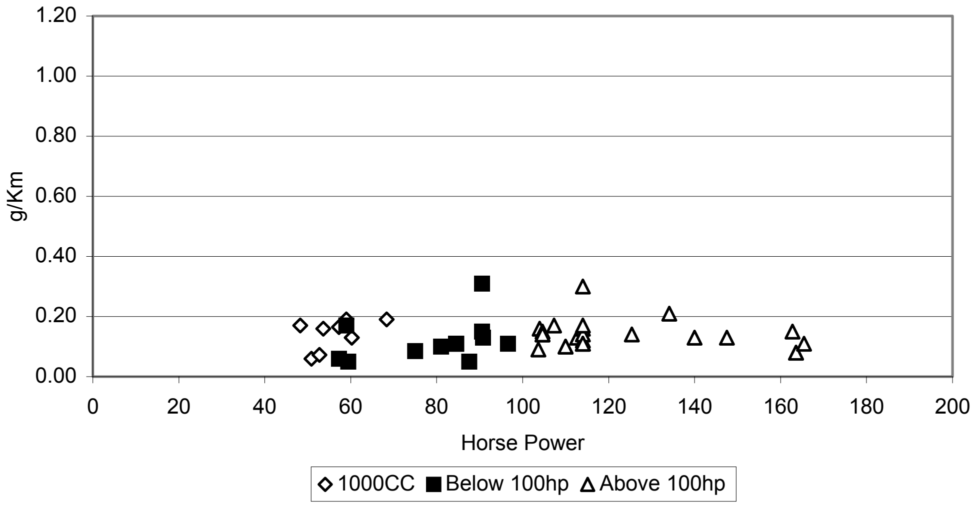
Compliance schedules and emission trends by car sizes

The evolution of compliance by car size can be observed in Graphs 1 and 2 where we present emission rates, by horsepower, for automobiles tested in 1992 and 1997. As can be seen, in 1992, most 'popular cars'(up to 1000cc) in the Brazilian market showed much higher emission levels than other car categories (up to 100 hp and above). This tendency was only reversed as the compliance time limit approached, in 1997.

**Graph 1: HC emission level by tax brackets in Brazil, 1992**



**Graph 2: HC emission level by tax brackets in Brazil, 1997**




In order to better describe the compliance trends, we undertake regression estimates of emissions of the three pollutants broken down by tax category, ie, small, medium and large. Controlling for rpm and horse power, it is possible to observe the evolution in the compliance trend by car category. Regression results are presented in Table 5.

**Table 5 OLS estimates of CO, HC and NOx emissions by automobile categories**

| | Log CO | | | Log HC | | | Log NOx | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Small** | **Medium** | **Large** | **Small** | **Medium** | **Large** | **Small** | **Medium** | **Large** |
| Constant | 2.497* | 0.841 | 4.461* | -2.014** | -1.244* | 0.263 | -1.628* | -3.464* | 1.103** |
| | (1.218) | (0.634) | (0.876) | (1.171) | (0.629) | (0.633) | (0.793) | (0.610) | (0.606) |
| Horse power | 0.0002 | 0.005 | -0.024* | 0.043 | 0.008* | -0.014* | -0.002 | 0.00004 | -0.003 |
| | (0.024) | (0.004) | (0.003) | (0.025) | (0.004) | (0.002) | (0.015) | (0.004) | (0.002) |
| Rotations per minute | -0.0001 | 0.00005 | -0.00008 | -0.00008 | -0.00002 | 0.00009 | 0.0003** | 0.0005* | -0.0002* |
| | (0.0001) | (0.0001) | (0.0001) | (0.00009) | (0.0001) | (0.0001) | (0.0001) | (0.0001) | (0.0001) |
| 1993 test | -0.211 | 0.050 | -0.083 | -0.271 | 0.049 | -0.147 | -0.217 | -0.003 | -0.123 |
| | (0.384) | (0.080) | (0.220) | (0.258) | (0.064) | (0.157) | (0.248) | (0.116) | (0.186) |
| 1994 test | -0.302 | 0.034 | -0.259 | -0.420 | 0.069 | -0.248 | -0.190 | -0.033 | -0.103 |
| | (0.427) | (0.085) | (0.220) | (0.368) | (0.069) | (0.169) | (0.322) | (0.117) | (0.180) |
| 1995 test | -0.175 | -0.161** | -0.361** | -0.167 | -0.075 | -0.350* | -0.286 | -0.118 | -0.114 |
| | (0.376) | (0.088) | (0.199) | (0.248) | (0.075) | (0.150) | (0.209) | (0.112) | (0.160) |
| 1996 test | -0.793* | -0.350* | -0.595* | -0.708* | -0.179** | -0.494* | -0.558* | -0.271* | -0.251 |
| | (0.375) | (0.118) | (0.192) | (0.300) | (0.097) | (0.146) | (0.200) | (0.115) | (0.162) |
| 1997 test | -2.066* | -1.784* | -1.193* | -1.945* | -1.425* | -0.965* | -1.221* | -0.989* | -0.585* |
| | (0.392) | (0.171) | (0.217) | (0.273) | (0.139) | (0.139) | (0.284) | (0.161) | (0.179) |
| Number of observations | 37 | 241 | 166 | 37 | 241 | 166 | 37 | 241 | 166 |
| Adjusted $R^2$ | 0.61 | 0.43 | 0.37 | 0.50 | 0.41 | 0.30 | 0.51 | 0.20 | 0.09 |

Notes: White heteroscedasticity consistent standard errors and covariance. Standard errors in parentheses. Small cars correspond to 1,000cc. Medium cars are higher than 1,000cc, but lower than 100hp. Large cars are higher than 1,000cc and 100hp.

* Statistically significant at the 5% level.

** Statistically significant at the 10% level.

A relatively well-fitted regression is obtained, especially for small and medium cars, even though the number of observations for small cars is quite low. For most pollutants and car categories, we could not reject the null hypothesis of no significant statistical difference in average emissions between 1992 and the 1993-1995 period. For 1996 and 1997 most pollutants and car categories showed significant reductions in average emissions. This result was expected, implying that most car manufacturers waited, on average, until the last year to adopt pollution control technologies. This result is similar to the one obtained by Kahn (1996) for the US where he finds that significant reductions in emissions are closely related to more stringent regulation periods.

Although in 1992 small cars (1000 cc) had the highest emission levels, they showed the fastest adjustment in emission reductions during the 1992-1993 period, once controlling for different rpm. In 1993, average CO emissions decreased by 19%, HC by 23.7%, and NOx by 19.5%. These were much higher than reductions undertaken by medium and large cars. Nevertheless, this adjustment process was not continuous and by 1995 average emissions increased by 10% for CO and 19% for HC. Adjustment towards the 1997 PROCONVE standards was mostly taken in 1996. Small cars reduced average emissions of CO and HC by approximately 35% from 1995 to 1996 and 30% to 35% from 1996 to 1997. NOx reductions were more stable, but the greatest reduction also occurred from 1996 to 1997.

As previously stated, small cars were, on average, the dirtiest models in 1992. Since then, they presented the greatest reductions in overall emissions, with a 87% reduction in CO, 85% in HC and 70% in NOx emissions, once controlling for different rpm.

Manufacturers started the technology adjustment in medium cars later, although their final reductions were slightly lower than in the case of small cars. By 1994, average emissions increased by 3.5% for CO and 7.2% for HC emissions, although NOx emissions were, on average, reduced by 3.25%. Nonetheless, after 1995, average emissions decreased substantially, particularly from 1996 to 1997 when CO and HC average emissions decreased, respectively, by 53% and 60%.

In contrast with other countries, large cars in Brazil were among the cleanest models in 1992. This was probably due to the subsidy offered for electronic fuel injection adoption. Since then, average emissions reductions have been much lower than small and medium cars. Some intensification occurred as the PROCONVE 1997 deadline approached with further average reductions of 70% for CO, 62% for HC and 44% for NOx emissions.

These differences in compliance schedules may be explained by the fact that, in order to attract consumers to low power models, the industry tried to keep prices down by not incorporating expensive technologies, such as electronic fuel injection which would have made ‘popular’ and medium cars cleaner, but 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) use 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, but more advanced technologies such as electronic fuel injection affected costs significantly. Moreover, these additional costs of introducing fuel injection were passed to consumers.

Using a hedonic price analysis, Fonseca (1997) estimates a quality index for the Brazilian automobile industry. 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. That is, the costs of technological improvements in cars were passed through to consumer prices, as one would expect in an oligopolistic market.

**Emissions and characteristics in the 1997 models**

The pattern of emissions across models and engine sizes changed considerably from 1992 to 1997. After the adjustment to the 1997 PROCONVE standards, this relationship changed when 1997 car models incorporated the existent technological devices.

Our results in Table 6 show that, after controlling for rpm, fuel type and single-point fuel injection, emissions tend to increase with horsepower. Moreover a unit increase in horsepower increases emissions by 0.002% to 0.004% depending on the pollutant analysed. Nevertheless, this linear increasing relationship between emission and horse power is not generic. We also estimated a quadratic model which was found significant for CO emissions which seems to follow an inverted-U shaped curve, first increasing and then decreasing with horse power. This finding differs from the ones obtained by Fullerton and West (1999) showing an opposite relationship.

Although for the linear model horsepower is not a significant determinant of CO emissions, it is statistically significant for HC and NOx. On the other hand, single-point and gasoline dummies are statistically significant for almost all pollutants. We find that, on average, single-point fuel injection cars emit 73% more CO than multi-point fuel injection cars and 58% more NOx, after controlling for rpm, horsepower and fuel type. For HC, the difference between multi-point and single-point fuel injection does not seem to be significant in explaining average emissions.

Another interesting result is related to the difference between gas-fueled and ethanol-fueled vehicles. Although ethanol-fueled vehicles make up an increasingly small part of the market, they still have lower CO and NOx average emissions than gasoline-fueled cars. On the other hand, we find that, after controlling for rpm and horse power, ethanol-fueled vehicles emit, on average, 36% more HC than gasoline-fueled vehicles with multi-point fuel injection (the most advanced technology for reducing emissions currently adopted in Brazil).

**Table 6: OLS estimates of emissions by automobile characteristics**

| Independent variables | Dependent variables | | |
|---|---|---|---|
| | **Log CO** | **Log HC** | **Log Nox** |
| Constant | -1.38 | -4.34* | -2.03* |
| | (7.84) | (5.86) | (7.72) |
| Horse Power | 0.002 | 0.003** | 0.004* |
| | (0.20) | (0.17) | (0.19) |
| RPM | 0.0001 | 0.0004* | -0.0002 |
| | (0.87) | (0.63) | (0.83) |
| Single-point | 0.547* | 0.187 | 0.46** |
| | (0.30) | (0.20) | (0.31) |
| Gas | 0.293* | -0.454* | 0.43* |
| | (0.09) | (0.06) | (0.11) |
| Number of observations | 67 | 67 | 67 |
| Adjusted $R^2$ | 0.14 | 0.37 | 0.23 |

Notes: Standard errors in parentheses.
* Statistically significant at the 5% level.
** Statistically significant at the 10% level.

Although our analysis is limited due to the lack of a complete database on car characteristics, we find that multi-injection devices may be an important technology to be adopted for further pollution control levels for Brazilian new car models.

# Concluding Remarks

Average emissions from cars produced in Brazil decreased substantially with the imposition of mandatory car emission standards. The compliance trend shows interesting adaptation schedules among car sizes and fuel types. Nevertheless, the gradual compliance approach of PROCONVE, based on the 1992 and 1997 deadlines, avoided a rapid introduction of already existing emission control technologies. During the middle years of the period 1992-97 models differed substantially in emission levels. Ethanol cars lost significant market share and are currently hardly sold. This was reflected in their compliance schedule which did not incorporate new technology as fast as gasoline cars. Compared to gasoline models, they still have lower average emissions for CO and NOx, but higher levels for HC.

Car tax structure subsidising large cars with fuel injection devices allowed this segment to speed up compliance. Conversely, small cars, due to their low price characteristic, had the slowest compliance schedule across all categories. However, after the adjustment to full compliance, they became the least polluting category in terms of average emissions. Therefore, we conclude that the current value added tax structure is not running against the emission pattern of manufactured Brazilian cars. Can this tax structure be modified to create additional incentives for lower emission levels in the current models?

With the full enforcement of PROCONVE in 1997, vehicle manufacturers do not have any further incentives to reduce emissions. Moreover, demand for new automobiles is still very high, increasing aggregate emissions with substantial pressures on air quality in major urban areas. In order to mitigate this problem, additional policy actions are required to create incentives for a cleaner profile of the Brazilian vehicle fleet. The idea of combining fuel taxes to decrease miles driven with a vehicle characteristics tax in order to encourage the purchase of cleaner automobiles was discussed and it is recognised as a cost-effective solution.

Since the current automobile policy regime is already offering wide tax incentives, a possible alternative is a tax discrimination between a clean and dirty car tax within each tax bracket based on clean-car characteristics, such as the multi-injection devices as pointed out in our econometric analysis. The application of this scheme for all categories would change the relative price of clean and dirty cars throughout all market sectors and will create incentives for the purchase of cleaner vehicles. Additionally, incentives for R&D in cleaner technologies would be induced. Note that this differentiation could be used alongside the already adopted tax differentiation across small, medium and large cars.

An important question relates to the neutrality of such a tax differential. Although in theory we could design a fiscal-neutral policy, the final result would depend fundamentally on relative elasticities across sizes and models, as well as the supply response to such a tax policy.

In spite of the fact that a subsidy on cleaner automobiles was given to fuel injection in the past, the choice among a tax on dirty cars or a subsidy on cleaner models does not depend solely on fiscal constraints. Subsidies for environmental purposes create substantial negative dynamic supply side responses.

The proposed characteristic tax can also be applied to annual licensing taxes (IPVA) creating an additional incentive for the substitution of dirty for cleaner used cars. There are some distributive concerns with that tax scheme since older and more polluting cars are usually owned by lower income households which would pay higher taxes.[16] Nonetheless, in a dynamic perspective, the lower tax on newer cars could create an additional incentive for richer households to buy new automobiles more frequently generating a reduction on used cars average prices. In that case, net welfare gains may arise for lower income households.

Another policy aiming at avoiding equity problems on the pursue of the fleet modernisation is a car sale tax rebate offered to new buys and linked to the selling of an old car varying according to car's age.

Regardless of the option, any taxation scheme based on clean car characteristic has to be reviewed periodically following the adaptations and innovations of these characteristics in the car market. Moreover, the dirty surtax levels must be somehow related to the marginal production costs of introducing these characteristics and also to the expected additional costs born by owners due to car maintenance and performance affected by these clean characteristics. In sum, although these cost-effective instruments are simple in theory, they are not easily implemented and should deserve further research efforts.

[16] See Harrington et al. (1994) for the analysis of the case of United States.

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