Diffusion of new automotive technologies for improving energy efficiency in Brazil’s light vehicle fleet

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**ABSTRACT**

Historically, Brazil has promoted the development and sales of light duty vehicles running on ethanol (firstly, ethanol-dedicated cars, and recently flexfuel cars). In the 1990s, the country also favored the sales of compact cars to middle and low-income classes. However, in the last years, the profile of vehicles sold in Brazil has converged towards larger and less-efficient vehicles. In 2008, Brazil launched the vehicle labeling program. Based on the outcomes of the historical programs oriented towards the development of automotive innovations, and on a survey conducted with the country’s main auto makers, this article evaluates whether the vehicle labeling program will both improve the energy efficiency of light vehicles, and introduce new technologies. Our results indicate that, despite its virtuous intentions, the program will not control the tendency of rising fuel consumption of passenger cars sold in Brazil. Therefore, other policies are needed to boost innovations in Brazil’s automotive industry.

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1. Introduction

Brazil and other emerging countries 1 are expecting expansive growth in the transportation sector in the coming years. The number of inhabitants per vehicle in Brazil (7.4) is high when compared to the United States (1.2), France and Japan (1.7). Among other Latin American countries this ratio is 4.1 in Mexico and 4.8 in Argentina (ANFAVEA, 2009). According to IEA (2006), the number of passenger cars in Brazil is expected to nearly triple from 2005 to 2030.

Brazil’s new vehicle sales have increased by approximately 9% per year over the last ten years. New licensing of light duty vehicles increased by 12.4% in 2008 over 2007 (ANFAVEA, 2009). The country has improved by three positions in the rankings of the worldwide vehicle manufacturers, moving from 9th to 6th position. In addition, it has moved from the 8th to the 5th position in the number of licensed vehicles. Exports decreased during the last years 2 (ANFAVEA, 2009).

Brazilian consumers of new light vehicles have limited access to data concerning these vehicles. On the other hand, purchasers of heavy-duty commercial vehicles have greater access to such data, as they exert a considerable influence in operating costs. In recent years, some factors, such as the average horsepower and weight of the new vehicle fleet have significantly increased (Borba, 2008; Nogueira and Branco, 2005). As a result of these trends – the growth of the transport sector, together with changes in the fleet profile – the transportation of passengers may be transformed into a more energy intensive activity.

In 2008, the Brazilian government established the Brazilian vehicle labeling program, aimed at improving the energy efficiency of new light vehicles. Vehicle labeling programs have been adopted in several countries 3 since the end of the 1970s with the purpose of making available information on the energy efficiency and/or CO2 emission levels of new vehicles, thereby encouraging consumers to purchase more efficient vehicles.

In view of the influence of the auto makers on the effectiveness of the labeling program, a survey was conducted among the eight largest Brazilian manufactures, responsible for more than 90% of new vehicle sales. The survey consisted of a questionnaire and interviews with the representatives of the certification and/or engineering departments of these companies.

References

1. IEA (2007) projected that the total number of vehicles in China and India will reach 270 and 295 million, respectively, by 2030.
2. Besides the increasing expansion of exports from Asian manufacturers, the appreciation of the Brazilian currency, the Real, and the construction of new car plants in developing countries previously supplied by Brazilian factories (e.g. Eastern Europe) were the main reasons for the fall in the Brazilian light-duty vehicles exports (Olmos, M., 2000).
This article evaluates whether Brazil’s new light vehicle labeling program is likely to become an effective policy for improving the energy efficiency of the light duty vehicle fleet, as well as encouraging the adoption of new automotive technologies.

Firstly, the paper assesses the record of adoption of innovation by the Brazilian automotive industry, in response to three governmental programs that were implemented in the last three decades: the promotion of ethanol-powered vehicles, incentives for the production of small-engines automobiles and incentives for the diffusion of flexfuel engines. Then, the paper analyses the design of the vehicle labeling program. Finally, the paper summarizes and evaluates the automotive industry’s point of view regarding the program, taking into consideration its rules, the obstacles to manufacturers’ compliance, the impact on the industry’s product development and the estimated period of time required for the introduction of new technologies in the Brazilian market.

2. Technology innovation drivers in the Brazilian automotive industry

Governments possess a variety of options for stimulating technological innovation. Christiansen (2001) mentions the typology of Vedung (1998), which summarizes the measures that foment the diffusion of new technologies in three categories, according to the restriction or coercion level. Such measures are based on laws and regulations\(^4\) (“Sticks”), economic instruments\(^5\) (“Carrots”) and persuasion\(^6\) (“Sermons”), and are part of the list of public policies that have been introduced by several countries to improve the energy efficiency of their vehicle fleets (Greene et al., 2005).

Another classification of public policy instruments was developed based on the wide recognition of the role of technology in economic growth (Solow, 1956). In addition to following the logic of the neo-Schumpeterian authors, governments can encourage the embrace of innovation through technology-push and market-demand pull initiatives, which are “measures that reduce the private cost of producing innovation (technology-push), and measures that increase the private payoff to successful innovation, (market-pull)” (Nemet, 2009).

The technology-push model, which goes back to Schumpeter’s (1947) first writings, depicts the typology of the technological change life cycle in terms of the stages of invention, innovation and diffusion (Christiansen, 2001). Based on this model, one of the key roles of public policies is to provide funds for R&D activities. Other examples include tax incentives for companies that invest in R&D, support for education and training and financing of projects or prototypes.

\(^4\) According to Vedung (1998), the coercive character of the regulation can be interpreted as a measure of technological pressure, as certain specific mandates of change in behavior or technological performance are introduced. In this sense, there is evidence that several regulatory programs promoted the increase in private R&D investments, and contributed to the development of new technologies. At the same time, the difficulty in defining an appropriate agreement for different companies and technologies, as well as the updating of the rules or standards can be hindered by the slow and intermittent nature of the regulation definition and implementation process (Christiansen, 2001).

\(^5\) Unlike the more restrictive nature of the command and control instruments, the main purpose of the economic instruments is to induce technological development through a cost-effective engagement through taxes, subsidies, permissions, rebates and others.

\(^6\) The information category utilizes persuasion to motivate changes in the consumption standards and behavior. The success of this last instrument will depend on the cultural and political variables of the country where it will be implanted, as well as on the industrial sector policies.

In the market-pull model, investments in innovation are induced by market needs and opportunities for an increase in sales for companies that offer products in response to latent consumer demand. Changes in market conditions create opportunities for companies to invest in new products to fulfill unmet consumer needs and also affect the size of the investment in innovation as a whole. In the specific case of energy technologies, changes in the prices of conventional sources of energy affect the demand for innovation both of the processes of energy production, as well as for the products and equipment that consume energy (Nemet, 2009).

Both the technology-push and the market-pull models represent extreme positions in terms of identification of the causes and sources of technological change. In general, the technology-push model has a larger impact on the earlier phases of the technology life cycle, while the influence of the market-pull model is stronger in the more advanced phases of the cycle (Christiansen, 2001). Mowery and Rosenberg (1979) assert that demand is more effective in motivating incremental technological change than radical change, and, for this reason, fails in stimulating the most important innovations. According to Nemet (2009), the technology-push model fails when mapping the market conditions and the market-pull ignores the technological capabilities (Nemet, 2009).

Several authors assert that these two mechanisms interact and are both necessary to prompt innovation. According to Freeman (1974), empirical evidence has shown that both approaches are relevant and should be introduced at the same time. Mowery and Rosenberg (1979) emphasize that it is important to consider both market demand and technological opportunity as necessary, but not sufficient, for innovation. Both models must co-exist, in addition to the existence of a range of other important incentives that are part of the innovation process.

Actually, some elements of both the technology-push and market-pull policies are identified in the most important government programs that have influenced the automobile industry in Brazil, as this paper will describe below.

2.1. The promotion of Brazilian ethanol-powered vehicle

The diffusion of the ethanol-powered vehicle in Brazil was promoted by the National Alcohol Program, whose main objectives were to reduce the country’s dependence on oil imports and reduce its trade deficit (Goldemberg et al., 2004). In the period between 1975 and 1979, the first stage of Alcohol Program was implemented with the objective of using anhydrous ethanol as a substitute for 20% (on a volume basis) of the gasoline consumed by the country’s light vehicle fleet. Only in the second stage of this program (1979–1985), the first car models powered on hydrated ethanol (100% on a volume basis) were launched (Souza, 2006).

Based on the results of Figueiredo (2006), the diffusion of ethanol powered vehicles in Brazil can be divided into three phases. In the first phase (1979–1981), when the first ethanol-powered models were launched, several technical problems related to the conversion of gasoline engines became apparent due to the lack of commitment to engine development on the part of the main automobile manufacturers. The second phase (1982–1983) was characterized by the opportunity of the automobile industry to recover sales (after the market retraction at the beginning of the 1980s), as well as the development of technological solutions. The third phase (1983–1985) is characterized by the broad dissemination of the ethanol powered car.

In the first diffusion phase, the government strategy to stimulate the ethanol powered vehicles began with the conversion
of the official fleet\textsuperscript{7} and introduction of a chain of technical services for the conversion of gasoline engines, through the accreditation of vehicle conversion workshops, based on the recommendations of government research institutes. However, ethanol-powered vehicles converted by the accredited chain presented several operational problems, which were corrected some years later, such as cold starting problems, undesired heating of the intake manifold, corrosion of the materials and blockages resulting from corrosion products, among others (Figueiredo, 2006).

At the same time, the primary auto makers lacked confidence in the government’s commitment to the Alcohol Program. Questions regarding several aspects of the program, such as the maintenance of the favorable relationship between the prices of gasoline and hydrated ethanol, the quality of ethanol sold though fuel pumps and the governmental commitment to the steady supply of ethanol. In addition, having two different engines for the same car model on the assembly line represented a cost increase, contrary to the multinational car makers’ idea of developing a “world car” concept (Silva and Fischetti, 2008). Thus, the first ethanol vehicle prototypes were developed by smaller manufacturers based in Brazil, such as Gurgel, Willys, Dodge, while some models were adapted by CTA.

Some authors (Figueiredo, 2006; Silva and Fischetti, 2008) assert that ANFAVEA\textsuperscript{8} was pushed to produce hydrated ethanol-powered cars only when the Brazilian government approached Toyota, proposing the construction of a passenger car factory in Brazil and accepting the Japanese company’s demand for production exclusivity of ethanol cars in the country. In view of that situation, in September of 1979, the government and ANFAVEA signed an agreement by which the manufacturers would research new technologies for the production of vehicles run on hydrated ethanol. Some months later, the first such car was launched by Fiat, a manufacturer that had recently opened a factory in Brazil. The first cars introduced in the market between 1979 and 1980 were beset with numerous imperfections, such as engine function irregularity and corrosion problems in the fuel reservoir and fuel pump, filters, carburetors and ducts.\textsuperscript{9} These issues were only resolved in the second phase of diffusion of the alcohol-powered car. The tests conducted at that time (Figueiredo, 2006) indicated that until shortly before the release of the first ethanol-powered vehicle, the manufacturers’ research was not yet complete, and tests to reduce engine operational problems were still being conducted. Some of the materials developed by car parts manufacturers (following the manufacturers’ specifications), were nothing more than adaptations of the gasoline-powered car versions, such as the use of the Zamak alloy\textsuperscript{10} (Figueiredo, 2006).

In an attempt to solve those problems, the government has instituted strong incentives since the commercialization of the first models. The pump price of hydrated ethanol was fixed by the government at 59% of the gasoline price, and an exemption from the tax on industrialized products (IPI) for ethanol fueled cars for the period of one year was also granted. Credit and longer financing periods for the purchase of ethanol cars were also provided to Brazilian consumers (Figueiredo, 2006).

With the intensification of the economic crisis\textsuperscript{11} in the country in 1981, the ethanol car represented a good opportunity for the manufacturers to overcome the automotive sector decrease in sales. The technological solutions appeared with the release of Corcel II by Ford in 1981, with a significant involvement of Brazilian engineering in the car design.

The Corcel II provided the advantages of cold-starting (with gasoline injection commanded by an automatic temperature sensor), use of nickel coating in carburetors and fuel pumps replacing bi-chromatization,\textsuperscript{12} and the use of liners more resistant to ethanol-corrosion in the fuel tank. The collaboration of several state research institutes\textsuperscript{13} was also important in the resolution of the corrosion problems (Figueiredo, 2006; Silva and Fischetti, 2008).

Fig. 1 presents the major improvements implemented to allow the use of ethanol-powered cars between 1975 and 1995.

The period between 1983 and 1985 represents the apex of the ethanol car diffusion process, characterized by the expansive growth in sales that reached about 96% of total new passenger cars sold in Brazil by 1985 (ANFAVEA, 2009). At that time, the lack of incentive policies for boosting energy efficiency of ethanol vehicles was evident. The only purpose was to maintain the average mileage for alcohol-powered vehicles at 80% as compared to that of gasoline powered cars. This control was made through Commitment Agreements signed by the manufacturers (Figueiredo, 2006).

In 1986, a decrease in international oil prices combined with the need for greater subsidies to maintain the artificial relationship between the ethanol and the gasoline prices started to hinder the economic viability of the Alcohol Program. The hydrated

\begin{itemize}
  \item \textsuperscript{7} Ten state companies, supervised by CTA (Aeronautical Technical Center), authorized the conversion that totaled approximately 746 vehicles (Silva and Fischetti, 2008).
  \item \textsuperscript{8} ANFAVEA is the Brazilian Automotive Industry Association.
  \item \textsuperscript{9} Indeed, some materials degrade in contact with fuel ethanol blends having high alcohol concentrations. Zinc, brass, lead and aluminum are sensitive metals. Terne (lead-tin-alloy)-plated steel, which is commonly used in gasoline fuel tanks, and lead-based solder are also incompatible with neat ethanol vehicles. The use of these metals should be avoided because of the possibility of fuel contamination and potential difficulties with vehicle driveability. Nonmetallic materials that degrade when in contact with fuel ethanol include natural rubber, polyurethane, cork gasket material, leather, polyvinyl chloride (PVC), polyamides, methyl-methacrylate plastics and certain the thermostet plastics (Sákalo et al., 2007).
  \item \textsuperscript{10} Zamak alloyed with other basic elements such as Aluminum, Magnesium and Copper. The use of Zamak alloy was not appropriate in carburetors for ethanol-powered cars (Figueiredo, 2006).
  \item \textsuperscript{11} The recession at the beginning of the 1980s is related to the 2nd oil crisis, which deepened the assembler’s difficulties.
  \item \textsuperscript{12} Electrochemical process of depositing a layer made of zinc and chromium on a substrate of steel and iron (Yassuda, 2006).
  \item \textsuperscript{13} Especially the Institute of Technological Research (IPT). The main action known as “Corrosion Protection Program” sponsored by MCI-STI involved IPT, COPPE/UFRJ, IAA, FTE, UFSCar (Figueiredo, 2006).
\end{itemize}
ethanol supply shortage that happened in 1989 deepened the lack of consumers’ trust in the program.\textsuperscript{14} In the middle of the 1990s, the manufacturers practically abandoned the production of ethanol cars (ANFAVEA, 2009). Fig. 2 shows a sharp drop in the consumption of hydrated ethanol\textsuperscript{15} in subsequent years, while anhydrous ethanol consumption continued to grow because of its addition\textsuperscript{16} as additive to gasoline.

In sum, both technology-push and market-pull policies were used to promote the ethanol-powered vehicle. Firstly, the technology-push policies were used in the Alcohol Program, and then market-pull measures were strongly applied to guarantee the economic viability of ethanol cars until such mechanisms ceased to be viable due the fall in oil prices.\textsuperscript{17} On the other hand, there was a lack of technology-push measures aimed at continuously improving ethanol car efficiency, due to the lack of long-term R&D resources specific to ethanol engines, parts and equipment of the native parts industry, as well skilled labor training. This happened because the primary Alcohol Program objective was to promote the production and sales of ethanol in order to reduce oil imports.

2.2. Incentives for the production of small-engine automobiles ($<1000\text{ cm}^3$ vehicles)

The policies of exemption from industrialized product tax (IPI)\textsuperscript{18} for cars of low cylinder displacement had a great impact on the Brazilian automobile manufacturers’ local strategies, especially on product development activities. At the time they were launched, automobiles having 1000 cm$^3$ cylinder capacity were very basic vehicles, lacking most accessories,\textsuperscript{19} but they were able to fill the great pent-up demand of the middle-class and low-income Brazilian population for automobiles that, up to that period, tended toward the purchase of used automobiles, similarly equipped (Consoni, 2004; Szklo et al., 2005).

\textsuperscript{14} The ethanol shortage crisis was caused mainly by the discontinuation of government subsidies to the alcohol/sugar production sector, combined with sugar price spikes in the international market (Moreira and Goldemberg, 1999).

\textsuperscript{15} Anhydrous ethanol has 0.5% by volume of water content, while hydrated ethanol has 5%. After the launch of flexfuel vehicles in 2003 (Section 2.3), the sales of hydrated ethanol rebounded strongly.

\textsuperscript{16} Since 1978, the mandated addition of anhydrous ethanol to pure gasoline in Brazil has varied between 20% and 25% (on a volume basis).

\textsuperscript{17} There was also a wide readiness of resources for the agricultural and industrial production of ethanol fuel through the technology-push and market-pull policy measures.

\textsuperscript{18} In 1993, the Brazilian government reduced the IPI tax rate from 14% to 0.1% (Szklo et al., 2005).

\textsuperscript{19} Air conditioning, power steering and other items associated with the driver’s comfort.

Actually, other countries, such as The Netherlands, Greece, Ireland and Italy, also adopted differentiated taxation measures for low cylinder capacity vehicles to stimulate the acquisition of automobiles with more economical engines and lower emissions (Mandell, 2009). However, this was not the primary objective of the Brazilian tax incentive measure, which instead aimed to increase sales and generate jobs in the country’s automobile industry (Consoni, 2004).

Geller et al. (2004) emphasize that the manufacturers did not focus on fuel efficiency of these cars. Initially the 1000 cm$^3$ engines sold were inefficient because of the obsolete technology employed, which was derived from old models of 1600 cm$^3$ cylinder capacity. In the mid of 1990s, there were some technological improvements that increased the energy efficiency of these vehicles, including the change from carburetors to fuel injectors and the introduction of multi-point electronic fuel injection. Since 1995, the 1000 cm$^3$ vehicles followed the tendency of the other vehicles in Brazil, acquiring greater power and torque. Fig. 3 shows the average fuel economy\textsuperscript{20} of new gasoline-fueled automobiles in the period between 1990 and 2004.

Auto makers made a significant effort to improve the performance of low cylinder capacity motors, focusing on increasing the compression ratio and using mechanical compressors. An example was the development of the 1.0 VHC (very high compression) engine, which resulted in increased horsepower and was patented by GM (Consoni, 2004). Borba (2008) also confirms the progressive power increase in 1000 cm$^3$ light vehicles that exhibited power less than 50 hp at the beginning of the 1990s, and today possess a rating of over 70 hp.

The manufacturers’ technological efforts to increase power pleased the Brazilian consumer, but reduced the fuel efficiency. After the consolidation of the sales of these 1000 cm$^3$ vehicles in the mid 1990s, the government increased the taxes\textsuperscript{21} levied on them.

The market share of these vehicles grew in the total percentage of the sales until 2001 (about 71%), but since then there has been a progressive decline,\textsuperscript{22} as shown in Fig. 4.

Therefore, the Brazilian incentive measure regarding the 1000 cm$^3$ car was based on tax incentives, or on a market-pull
Such a policy led to changes in the profile of the Brazilian light vehicle fleet, as well as changes in the strategies of the four main Brazilian manufacturers. For instance, GM, which historically centered most of its resources in the development of medium and high capacity cars, shifted its strategy towards compact vehicles (Consoni, 2004). Other manufacturers, such as Fiat, managed to increase their market share in the country after the introduction of compact vehicles.

In this case, the market-pull mechanism stimulated incremental innovations that led to the downsizing of the average automobile engine, and consequently a reduction in the size and weight of automobiles. After few years, as there were no incentives regarding fuel efficiency, the manufacturers’ development efforts returned to meeting consumer demand for increased power and comfort.

2.3. Incentives for diffusion of flexfuel vehicles

The flexfuel system developed in Brazil is an innovation which derived from the competence acquired in the development of the ethanol vehicles, through research accomplished by companies in the automotive parts sector, mainly Bosch and Magnetti Marelli. This technology started to spread at the end of the 1980s, when the US government promoted the development of engines run on methyl or ethyl alcohol (methanol and ethanol) and base-gasoline mixtures, beginning with the approval of legislation in 1988 (Alternative Motor Fuels Act). The pioneer company in the development of this technology in Brazil was Bosch, whose American branch earned a patent in 1988 for the technique of fuel detection through the use of an oxygen probe.

The research and development of the system by Bosch’s Brazilian engineering team began as a technological research project with a team of a few engineers, culminating in the development of a concept car based on the GM Brazilian model Omega 2.0. The technical knowledge previously obtained by the company’s Brazilian engineers during the development of ethanol injection system was fundamental for subsequent development of the flexfuel system.

In 1992, the company possessed the necessary infrastructure to meet the manufacturers’ demand for ethanol injection systems. But, with the strong drop in demand due to the indifference of consumers and manufacturers to ethanol cars, Bosch’s Brazilian team started to study a technical solution for the use of flexfuel engines (Quintão, 2008).

Bosch faced technical challenges in the development of the flexfuel system centered around three key components of the standard gasoline injection system: the electronic injection software system (electronic command unit), the spark plug and the electrical wiring, known as the wire harness, inside the fuel pump (Quintão, 2008; Szklo et al., 2007).
The product engineering team from the Gasoline Systems Division, with the aid of the German head office, developed internally not only the solution for the change in the spark plug, but also the solution for the electronic command unit. As to the electric wire harness, Bosch had to look for a supplier in the Brazilian market, because the component was not produced by the company. Given that the production scale was very small, no large supplier of that component was willing to develop a specific product for dual fuel application. This system was produced by Letandé, at that time a small Brazilian company. Letandé developed the component based on research into patents and scientific articles related to the subject.

The participation of GM in the development of the engine was small but important, providing the platform to test the concept (Quintão, 2008). Bosch also counted on the support of a technician from GM's engine division, which supplied the laboratory resources necessary for conducting the work at the manufacturer's premises. Between 1994 and 1998, Bosch also developed concept cars for Volkswagen and Fiat, with the objective of convincing manufacturers of the viability of the flexfuel engine in terms of torque and power increase with the use of ethanol mixed with gasoline.

Initially, the manufacturers were not persuaded to adopt the flexfuel system, asserting that they needed both tax incentives to compensate for the investments and assurances concerning the tax classification, the regulatory requirements and licensing criteria for vehicles equipped with the flexfuel system. However, in 2002, responding to the request of the automobile industry, the government extended the same tax treatment granted to ethanol vehicles to the flexfuel vehicles. In March 2003, Volkswagen commercially launched its first vehicle with the flexfuel system that used Magnetti Marelli SFS system. Soon afterwards, all the main Brazilian auto makers launched their own models using flexfuel technology. The market acceptance of these vehicles was such that sales reached about 87% of total sales of new light duty vehicles in 2008 (ANFAVEA, 2009), as seen in Fig. 5.

The flexfuel technology represents a cost reduction for the manufacturers, considering that it minimizes the production of a differentiated stock of parts, making possible the unification of several vehicle components, such as ignition wire harnesses, injection valves and fuel pumps that were previously differentiated by the type of fuel (Abreu and Ribeiro, 2006).

As to the consumer, the flexibility ensures autonomy in relation to eventual fuel shortage problems (as happened with the Alcohol Program), and can provide additional decreases in fuel costs.23 On the other hand, the flexfuel alternative, as implemented in Brazil, is not as efficient as single-fuel engines alternatives.

This occurs because the ideal combination of compression ratio, cylinder geometry and valve timing is different for each type of fuel. Additionally, the flexfuel engine is not able to take full advantage of ethanol's superior combustion efficiency, since the compression ratio of a flexfuel engine is lower than that of a single-fuel ethanol engine, due to the gasoline's lower octane rating (Szklo et al., 2007).

For instance, Szklo et al. (2007) showed that an optimized Otto-cycle engine burning a higher ethanol blend (E30) can be much more efficient than a flexfuel vehicle running with varying proportions of ethanol and gasoline. Actually, according to Nogueira and Branco (2005), with the advent of the flexfuel engines, the need to promote fuel efficiency of Brazilian vehicles is even greater, as they are less efficient when using ethanol. Fig. 6 shows the fuel economy24 for the new Brazilian flexfuel vehicle fleet between 2004 and 2008 (CETESB, 2008).

Between 2004 and 2008, there was an improvement in efficiency of flexfuel vehicles fueled with gasoline, while flexfuel vehicles fueled with ethanol have remained unchanged. Nevertheless, it is important to emphasize that most of the users run their flexfuel cars only on ethanol (EPE, 2009).26

The diffusion of the flexfuel technology in Brazil shows the evolution in the ability of the auto makers and automobile parts companies to undertake increasingly complex technological activities independent of their head offices. This technology

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23 Depending on the Brazilian state.
24 Based on the carbon balance method.
25 It was not possible to compare the average fuel economy of the flexfuel vehicles with the vehicles run exclusively on ethanol, because of the different methodology for the measurement of fuel consumption employed by CETESB (Environmental State Company); however, the average fuel economy of 1000 cm³ ethanol-powered vehicles evaluated by CETESB in 2004 was 8.8 km/l.
26 The Ten-Year Plan of the Brazilian Energy Research Company (EPE) for the period from 2008 to 2017 estimates that ethanol represent three quarters of the fuel consumed by the flexfuel vehicles (EPE, 2009).
strongly affected the automobile industry strategy and led to incremental innovations based on the technological knowledge acquired in Brazil. Once again, tax exemptions, which were identified by Nemet (2009) as a market-pull policy, boosted the diffusion of this incremental innovation in Brazil.

3. Analysis of the Brazilian vehicle labeling program

In 2008, the Brazilian government introduced a vehicle labeling program that was aimed at increasing energy efficiency for the new light duty vehicle fleet. This section evaluates the likelihood of this program of achieving its main objective and extent to which it may promote the introduction of new automotive technologies.

Among the vehicle labeling programs currently implemented worldwide, two basic systems stand out: non-comparative and comparative. The comparison factors (fuel consumption and/or CO\(_2\) emissions) are directly related to energy efficiency and are used according to the labeling program’s pre-established objectives, as well as the target audience for the program. Fuel consumption as a comparison factor primarily focuses on the economical aspect and operating costs, while the comparison factor based on CO\(_2\) emissions is driven by an audience concerned about environmental aspects.

One example of a comparative system was implemented in the United States, where a mandatory labeling program began in 1976 for all light vehicles sold in the country. The American system compares the fuel consumption of vehicles grouped according to internal volume categories for passenger cars and according to the use and gross weight for light trucks (EPA, 2006).

A non-comparative system was adopted in the European Union in 2001. The Directive 1999/94/CE stipulated as a minimum requirement for all member states the obligation to display information labels on specific fuel consumption and CO\(_2\) emissions. However, some countries, such as Belgium, Denmark, the United Kingdom and Portugal implemented systems of absolute comparative labeling (Abreu, 2007).

In Brazil, the voluntary vehicle labeling program (PBEV, using the acronym of program’s name in Portuguese) is a comparative relative system, in which participating manufacturers must divulge fuel consumption data for at least 50% of their models, but the display of fuel economy labels in showrooms is voluntary. Vehicles are classified in five classes of energy consumption (A through E), where class “A” is the most efficient. The vehicles are grouped in eight categories, four of which are based on end use: sports, off-road, light commercial and cargo vehicle (based on passenger car); and four are based on vehicle size: subcompact, compact, midsize and large.

Initially, the Brazilian labeling program could be viewed as an important step towards the future improvement of the country’s light duty vehicle fuel efficiency. However, some characteristics of this program can prejudice or delay the achievement of that objective. According to Wiel and McMahon (2003), the design of the label, the level of market support, and the level of effort of the government are key factors for the effectiveness of a labeling program. These key factors will be analyzed in the following sections.

3.1. Label design

The Brazilian car label layout is derived from current energy labels already adopted for household appliances in Brazil, presenting a fuel economy comparison in form of colored bars forming five classes. This layout enhances the vehicle label comprehension by consumers because most of them are familiar with the appliances labels.

The label’s content could also be considered simple, showing the year of program application, the vehicle category, vehicle model identification and the vehicle performance for city and highway in km/l or km/Nm\(^3\), well-known measures for ethanol/gasoline fuels and CNG for Brazilian consumers. Despite the simplicity of the label’s layout, the Brazilian label does not show the best information for purchasing an energy efficient car.

The relative comparative system allows the division of the vehicles in eight categories, in such a way that the lighter, heavier and powerful vehicles are compared in different ways. In addition to the four vehicle type categories, PBEV presents another

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27 In the non-comparative system, the labels present fuel consumption and/or CO\(_2\) emission without establishing a comparison with the other vehicles sold in the market. In the comparative system, the labels can present two types of comparison: absolute and relative. The former shows the vehicle energy efficiency in comparison with all types of lights vehicles sold, whereas the latter groups vehicles according to attributes or parameters, such as end use type, size, weight, power, cylinder capacity and others (Abreu, 2007; Plotkin, 2009).

28 Many countries had already implemented their own vehicle labels since the end of 1970s (Abreu, 2007).

29 Vehicle size is calculated based on vehicle footprint defined as vehicle length times vehicle width.

30 The vehicle’s identification is defined as brand, model, motor, transmission (MMMT).

31 The vehicle energy consumption is calculated in MJ/km, allowing comparison between different fuel types.
parameter of comparison (based on vehicle footprint) for passenger car categories, but excludes sports cars and SUVs. This type of relative comparison does not motivate the assemblers to alter their sales towards the development of lighter vehicles or to reduce power. It also can lead consumers to perceive that some models of a larger size category have higher efficiency rating despite having poorer fuel economy. On the other hand, some countries have chosen an absolute comparison for labeling and standards programs because this is a more accurate expression of how efficient the vehicle is and also motivates downsizing from larger to smaller vehicles. This is a critical issue, as the international experience with the light-duty vehicle fleet illustrates. For instance, in the European Union, despite the dieselization of European automobiles, the increase in weight of the European fleet was the main reason for not meeting the voluntary goal signed in 1998 of 140 g CO2/km by 2008, under the voluntary agreement (Cuenot, 2009). In the United States, the CAFE Program shows that the division into two different vehicle types might encourage the production of light duty and off-road vehicles as passenger cars (Geller et al., 2006; NRC, 2002; Turrentine and Kurani, 2007). Fig. 7 depicts the label adopted in Brazil.

Another aspect of PBEV criticized by smaller Brazilian auto makers is that the four passenger car categories overlap, due to the tolerance of ± 0.10 m². Table 1 exemplifies this issue.

The tolerance of ± 0.10 m² results in an overlap between each category. If the vehicle size falls within this overlap, the manufacturer can place the model within the most advantageous category. This particularly favors larger auto makers that have a greater variety of models. According to Raimund and Fickl (1999), an effective label should be resistant to manipulation, that is, it should not be possible to change the classification of a model by simple management by the manufacturer.

3.2. Market support

The compliance of the manufacturers is another key factor for the effectiveness of a labeling program. In the first year of the Brazilian program, only KIA effectively joined it, affixing the label on two models. Four other companies provide public information about their vehicles. Table 2 shows 31 models, among these 24 were classified in two categories (subcompact and compact) and were assigned to fuel efficiency classes. The remaining 7 models listed in Table 2 were not assigned to fuel efficiency classes because there was not the minimum number of vehicles required to make the classification.32

In addition to the low compliance of manufacturers, the number of vehicles labeled in the market may be insufficient to help consumers make a choice based in fuel efficiency. The Brazilian labeling

### Table 2

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
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</table>

Source: INMETRO (2009).

a Engine displacement.
b Ethanol.
c Gasoline.
d Cargo vehicle based on passenger cars.
program requires that participating assemblers divulge fuel consumption data for at least 50% of their models.

This allows the selection of the most economical cars, independent of the amount sold and their true impact on the fleet’s overall efficiency. Additionally, the participating assemblers are not required to display the label at the point of sale, and can opt to leave the program in the following year.

According to Wiel and McMahon (2005), penalties are needed to ensure that manufacturers, distributors and retailers comply. For instance, punishments for non-compliance could include removing the label from the manufacturer or public announcing the assembler’s non-compliance. Geller (2003) emphasizes that the application of penalties is an important factor for a successful labeling program, such as the risk of imposition of a mandatory regulation or the loss of tax incentives and other financial subsidies.

3.3. Government commitment

According to Wiel and McMahon (2003), after deciding the technical and legal aspects and procedures, the government should develop an implementation plan covering all aspects of the subsequent steps of the program. A number of related measures can increase the effectiveness of a labeling program, including: establishing compliance monitoring procedures, consulting with manufacturers to increase the commitment to the program, government promotion of the program by frequent public announcements, annual efficiency awards, public education campaigns, media promotion and publication of lists of current models on the market on the internet or in brochures (Wiel and McMahon, 2005).

The regulation governing the PBEV was approved in 2008 after some years of debate among institutions of the Federal Government, CONPET, and automobile assemblers (ANFAVEA). INMETRO is the coordinator of PBEV, and responsible for its implementation. CONPET is the Brazilian program to promote the rational use of oil and natural gas. Petrobras (the Brazilian Oil Company) coordinates CONPET, and was a major agent in the formulation of PBEV, especially for establishing the comparison parameter for passenger cars. Interestingly enough, Petrobras as an oil company whose main focus is to sell oil products to the Brazilian market should have seen PBEV as a potential loss of revenue. However, the major stakeholder of Petrobras is the Brazilian government who considers Petrobras as an agent for implementing the country’s energy policies in the fuel sector.

Nevertheless, the commitment of the Brazilian government could have been more effective. While there have been meetings with manufactures in order to convince them to participate in the program, other actions, such as promotion of the program through public awareness campaigns, have not been undertaken. Currently, there are two lists showing the vehicle performance of some cars in INMETRO and CONPET website.

On the other hand, the international experience provides good examples of successful programs. For instance, according to the government action to promote the voluntary energy efficiency program in the Netherlands was quite different. In the 1990s, the Dutch government encouraged manufacturers to develop a plan to improve energy efficiency whenever technically and economically viable. The companies also agreed to report their progress annually. The government, in turn, granted tax incentives for investments in technologies, protection against obligatory regulations and financial subsidies (Geller, 2003).

4. Will PBEV promote new energy efficiency technologies in the Brazilian automobile industry?

The Brazilian light-duty vehicles market is divided among multinational manufacturers: the largest market slice (around 75%) belongs to the four companies first installed in the country (Fiat, Volkswagen, GM and Ford), followed by newcomers PSA Peugeot-Citroen, Honda, Renault and Toyota, as seen in Table 3.

The four main auto makers are characterized by less centralized investments in product development and some autonomy in relation to their head offices than the French and Japanese companies. One of the objectives accomplished by the newcomers was the consolidation of the production units in Brazil and the integration of the chain of local suppliers into the process, aimed at reaching a higher level of domestic production of automotive parts (Consoni, 2004).

As seen in Section 2, usually the main technology development in the automotive industry refers to incremental innovations. The auto makers’ technological strategies do not prioritize radical technological innovations or advanced technologies that require a long time horizon in Brazil. This conservative R&D investment profile is a consequence of the pattern of oligopolistic competition, market demand, and above all, the tendency to centralize the more advanced technological activities in the manufacturers’ countries of origin (Consoni, 2004).

The parts industry plays a fundamental role in the technological development of Brazil’s automotive sector, either from indigenous developments or those in co-development with the assemblers (Quintão, 2008). Indeed, as described before, the flexfuel system, electronic injection, anti-lock brakes (ABS) and GPS navigation system are some examples of technologies provided by these suppliers.

In 2008, about three million light-duty vehicles were produced in Brazil. Most of those vehicles (89%) were sold internally and about 87% were flexfuel vehicles (ANFAVEA, 2009).

Data on new vehicle energy efficiency is not publicly transparent in Brazil. There are major difficulties in obtaining fuel consumption data on the vehicles produced are large. No updated

<table>
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</table>


33 The test procedure of the Brazilian labeling program evaluates the vehicle energy consumption in the city and highway drive cycles according to ABNT Regulation NBR 7024:2008.

34 Regulation “Portaria INMETRO No. 391—November 2008”.

35 INMETRO (National Institute of Metrology, Standardization and Industrial Quality), ANP (Oil, Natural Gas and Biofuels National Agency), CETESB (Environmental State Company) and others.

36 Until the end of the 1990s, the technological activities were concentrated in the adaptation of platforms to the local conditions and, to a lesser extent, in the development of local models (derivative vehicles) from global platforms adapted to fulfill the Brazilian market (Consoni, 2004).

37 The passenger car fleet corresponds to 94% of flexfuel vehicles (ANFAVEA, 2009).
research measures energy efficiency and most manufacturers do not release information on fuel consumption in the vehicle owner manuals or other publically available information.

During the 1980s, information\(^{18}\) on new vehicle fuel consumption was published by the Fuel Economy Program (PECO), but with the decrease in oil price and strong pressure from auto makers to omit consumption data, that program was discontinued in 1986.

In order to evaluate whether the current Brazilian vehicle labeling program is an effective policy to improve the energy efficiency of light duty vehicles, as well as introduce new automotive technologies, a survey was conducted between June and September 2009 with the Brazilian eight largest auto makers,\(^{39}\) which are responsible for more than 90% of new vehicle sales. The survey consisted of a questionnaire and an interview with representatives of the certification and/or engineering departments of these companies. The questionnaire covered issues relevant to the impact of PBEV in the firm’s product development; the automotive industry’s point of view regarding the label design; the PBEV rules; the obstacles to assembler’s compliance with the program; and the government’s efforts and measures to incentivize the PBEV. The technologies assessed in this study were chosen from the National Research Council report (\textit{NRC, 2002}) which outlined several automotive technologies for better fuel economy.

According to the responses to the questionnaire, five auto makers found that PBEV was correctly designed. In their opinion, the strengths of the program are to increase the consumer’s perception of the vehicle efficiency and to provide an opportunity to improve the company’s image in the market. The drawbacks most cited were the division of vehicles into categories and the overlap between categories according to vehicles size limits.

However, this answer may not be reliable, since the PBEV has very flexible rules and does not require significant improvements in the car’s energy efficiency.

Six Brazilian auto makers reported that PBEV is seen as a factor that will accelerate the spread of new fuel economy technologies, due to the consumer demand for more economical cars and increased competition among the manufacturers. However, the introduction of PBEV still has not motivated auto makers to introduce improvements in the energy efficiency of their models. Only one company reported having modified one of their models to improve their ranking within the program.

At this point, there is no prospect for introducing more advanced technologies in the light duty fleet manufactured in Brazil. The new emergent technologies, such as direct injection, homogeneous charge compression-ignition (HCCI), downsizing and supercharging, camless valve actuation (CVA), variable compression ratio (VCR), cylinder deactivation and integrated start generator (ISG), will not be introduced in the near term.\(^{40}\)

Some engine and transmission technologies, such as variable valve timing (VVT), valve timing & lift control (VVT&L), five/six-speed automatic transmission and continuously variable transmission (CVT), have already been introduced in the Brazilian market before PBEV, but only in vehicles which have higher markup and little representation in the fleet. Although these technologies are already available and well known to the manufactures and their suppliers (\textit{NRC, 2002}), the auto makers reported that they are still not cost effective for most of the vehicle classes. A few improvements in aerodynamic drag, rolling resistance and vehicle weight reduction were also applied in the Brazilian fleet, but the investments were small as compared with the investments made in the auto makers’ countries of origin.

In addition, the auto makers pointed out the indifference and the lack of knowledge on the part of Brazilian consumers regarding energy efficiency as one of the factors responsible for the technological gap in the Brazilian market. However, not only in Brazil, but in many countries, most consumers do not usually evaluate the long term savings generated by lower fuel consumption and generally choose fuel pump prices, as well as vehicle comfort, size, design and power as the worthy vehicle attributes (\textit{Plotkin, 2009}).

According to auto makers, the strongest driver for technological improvements in fuel economy in Brazil is the global trend toward investments in lower polluting vehicles. The manufacturers highlight this trend by investing in the flexfuel engines, since ethanol results in less net CO\(_2\) emissions. Four companies emphasized that the benefits from flexfuel technology are more relevant to Brazil (from an environmental standpoint) than increases in energy efficiency through new technologies.

However, as described in Section 2.3, the flexfuel engine when compared with a single-fuel engines, actually provides lower energy efficiency. Additionally, increasing ethanol production requires more investments in infrastructure and can cause greater local environmental impact. According to Niven (2005), while ethanol consumption, by replacing gasoline, avoids CO\(_2\) emissions, it still contributes to several adverse environmental impacts, mostly related to local atmospheric pollutants. Therefore, reducing ethanol is also an important target.

Two companies mentioned that the use of ethanol could postpone the introduction of new technologies, due to its low price, mainly in Sao Paulo, the largest consumption center in the country.\(^{41}\) It was reported that consumers who want to save fuel prefer to supply their cars with ethanol.\(^{42}\) This fact confirms the conclusion of \textit{Diamond (2009)}, which pointed out that the fuel prices represent the most visible signal for consumers interested in fuel savings. An example is the significant change in driving habits that happened when the US gas prices reached $4.00 per gallon mark nationwide in 2008.

The risk of technological lock-in of the flexfuel vehicles (that was introduced in 2003 and that effectively began to spread in 2005) should be studied, mainly because the international automobile industry is investing massively in hybrid and electric vehicles (\textit{Ockwell et al., 2008}), as well as in advanced diesel-fueled vehicles in Europe (\textit{Cuenot, 2009}).

The lock-in phenomenon is explained by \textit{Arthur (1989)}: the more effort invested in a particular technological standard, the more difficult it becomes to change to an alternative, because this

\(^{18}\) In 1979, PECO was created by an agreement signed between the Brazilian government and the auto makers. This agreement aimed at decreasing fuel consumption of new light vehicles. The program was implemented by the Department of Industrial Technology of the Ministry of Trade and Industry (MCI/STI), which published between 1983–1986 indicators of fuel consumption of new light vehicles available on the market, and set consumption targets to be achieved gradually by auto makers (MCI/STI, 1983). According to Nogueira and Branco (2005), the energy efficiency targets of this program were achieved. However, although created in 1979, in practice PECO was only implemented in 1983, and the Program lasted for just 3 years.

\(^{20}\) Fiat, Volkswagen, GM, Ford, PSA Peugeot Citroen, Renault, Toyota and Honda.

\(^{40}\) A Brazilian expert from the ANFAVEA pointed out that advanced technologies will considerably increase the upfront cost of flexfuel vehicles, and this will undermine the acquisition of these vehicles by the Brazilian consumer (Joseph Jr., 2009).

\(^{41}\) Sao Paulo represents 33% of the new light vehicle market (ANFAVEA, 2009). In Sao Paulo State, the average pump price per liter of hydrated ethanol in 2009 was R$1.34, while the pump price per liter of gasoline was R$2.38.

\(^{42}\) If the price relationship between the ethanol and the gasoline sold in Brazil is about 70%, from the economical point of view it is advantageous to consume alcohol or gasoline, because of the difference in the calorific power. However, in several Brazilian States that relationship is higher than 70%. 

transition tends to be increasingly expensive as the established technology is further developed. Hence, one technology can prevail for a long period of time inhibiting the development and the introduction of alternative technologies, even if the latter are superior in several aspects. In this situation, there is little motivation to change technology, due to the amortization of investments, time spent learning the prevailing technology and economies of scale.

Therefore, it is not unreasonable to expect that the introduction of new advanced technologies, such as hybrid and electric vehicles, in Brazil could be delayed by the possibility of technological lock-in exhibited by the flexfuel vehicles. But the most important barriers to these new technologies are the high initial production costs and the lack of demand from consumers. The price premium of a hybrid vehicle is a common barrier to its adoption in several advanced markets (Diamond, 2009, Ockwell et al., 2008).

Seven auto makers agreed that hybrid vehicles can arrive in the medium to long term at the Brazilian market via importation, for a very small niche of consumers, but there is no provision for their manufacture. Other obstacles pointed out by the manufacturers are the production of components for hybrid vehicles by Brazilian auto parts companies, the training for repair shops and the investments in vehicle adaptations due to the Brazilian gasoline specifications. However, these barriers could be overcome since most of the parts companies are multinational corporations active in this technology in other markets, and they have proved their competence in adapting ethanol powered cars to Brazilian gasoline since the middle of the 1980s.

The assemblers also highlighted the lack of government measures which promote the importance of fuel economy. In fact, in Brazil, there are no technology-push policies to promote fuel efficient cars from the federal government. Aside from fuel taxes, the PBEV is the only market pull measure in this direction, but no federal incentives are introduced for fuel economy in the light-duty vehicle fleet. On the contrary, the high import tax and industrialized product taxes increase the cost of auto parts and components. Only on the state level, seven states granted the owners of vehicles powered by electric motors exemption from state vehicle excise tax.

There are many international examples of government initiatives which have encouraged demand and the production of hybrid vehicles and other fuel economy technologies. Two examples are a mandatory fuel economy and mandatory emissions standards for new vehicles in China.

The Chinese fuel economy standards pushed auto makers to bring the newest more efficient vehicles to consumers, reducing the efficiency and technological gaps between vehicles sold in China and those sold in advanced foreign markets (Oliver, et al., 2009). In the early 2000s, the vehicle weight and engine displacement of Chinese light vehicles fleet were almost 11% and 15% less respectively than the German and Japanese fleet, but the average fuel economy was 10% higher (Oliver, et al., 2009). The enforcement of emissions standards for new vehicles is considered as a key motivation for Toyota's decision to produce hybrid vehicles in China, in addition to other factors such as labor costs and access to export markets (Ockwell et al., 2008). In both cases, the regulatory measures drive auto makers to apply new fuel efficiency technologies. These are good examples what Onoda (2008) pointed out: that mandatory programs can produce satisfactory results if they are well designed. On the other hand, voluntary agreements have often fallen short of targets to improve fuel efficiency due to their non-binding nature (Cuenot, 2009).

There are also many market incentives that help to overcome the incremental initial purchase cost of hybrids. In Switzerland, the tax incentives on purchasing new cars have promoted a 20% increase in Prius purchases compared to other Toyota models (Ockwell et al., 2008). In the US, the federal government offered $400 to $3400 tax credit depending on vehicle model's emissions and its fuel economy (EPA, 2009).

According to Onoda (2008), differentiated financial incentives based on fuel efficiency or CO₂ emissions would be effective tools to stimulate demand for fuel efficient vehicles, particularly when coupled with strong, well designed labeling programs. A fuel economy label can be the criteria for other policy instruments such as tax deduction, loans by public banks, a fee for less fuel efficient cars and a rebate for very fuel efficient cars (Greene et al., 2005; de Haan et al., 2009). The adoption of these and other market-pull policies in Brazil may be necessary to boost technological innovations in the automotive industry.

5. Conclusion

The incremental innovations presented in this article for the Brazilian case were motivated mainly by market-pull policies, principally tax incentives. The tax measures spurred the Brazilian auto industry to introduce new technologies, as seen in ethanol powered cars, 1000cm³ car and flexfuel vehicles. They have changed the profile of the country's fleet and the strategies of the automobile industry. The technology-push policy was exemplified by the Brazilian Alcohol Program, but nowadays this type of policy plays a very modest role in innovation and technology dissemination.

Nevertheless, several reasons justify the diffusion of fuel efficient technologies in the Brazilian new light-duty vehicle fleet. Brazil is a growing automobile market and is currently the world's fifth largest market in licensing of new vehicles. In recent years, some factors, such as the power and weight of the new vehicle fleet, have significantly increased. Currently, almost all new light vehicles sold in Brazil have a flexfuel engine which presents lower energy efficiency compared with single-fuel engines. As a result, the growth of the transportation sector, together with changes in the fleet profile, could transform the transportation of passengers into a more energy intensive activity. In addition, ethanol produces several adverse environmental impacts, mostly related to local atmospheric pollutants.

The Brazilian government recently implemented a voluntary vehicle labeling program consisting of a low degree of restrictions and flexible rules, and which thus generated little commitment on the part of auto makers to improve energy efficiency. A mandatory program, like the fuel economy standards introduced in China, could be an alternative to promote the introduction of innovative technologies aimed at reducing fuel consumption over those which increase the vehicle's horsepower, size and acceleration.

The results of the survey conducted with the auto makers indicate that PBEV is still insufficient to control the tendency of rising fuel consumption of the new light-duty vehicles sold in Brazil. In sum, despite the labeling program's virtues, the adoption of other market-pull policies is needed to boost efficiency-focused technological innovation in the country's automotive industry.

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43 Brazilian gasoline contains 20–25% (volume basis) of anhydrous ethanol. Some adaptations comprise engine calibration, anti-corrosion treatment of ducts and internal piping and adaptation to emissions legislation.

44 The industrialized product tax plus import taxes could reach 60% (Gurgel, 2009).
In order to better understand the Brazilian experience with vehicle labeling, the authors also recommend a future survey about consumers’ awareness of PBEV and the use of the label to influence purchase decisions, as well as a future study to measure its evolution.

Acknowledgements

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