Faculdade de Economia, Administração e Contabilidade de Ribeirão Preto
Universidade de São Paulo

Texto para Discussão

Série Economia

TD-E 01 / 2010

Quantifying the Benefits of Multifuel Cars: An Application of Random-Coefficients Logit Model

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Abstract

This paper tries to measure the welfare gains from technological innovation, focusing on the most important technological breakthough of Brazilian auto industry during the last decade: the so-called "flex-fuel" cars, able to operate using various fuel types. In order to do that, initially a review of the literature was carried out, both on the evolution of the technolgy as well as on the valuation of new goods. On the empirical part, an econometric estimation of a demand relation using Random Coefficient Logit model, on the other hand led to a welfare estimate, for the perfect competition assumption, of about 1.2 thousand Reais per family, in the same period, using the perfect competition assumption and just one thousand assuming differentiated products competition.

Resumo: Este artigo tem por objetivo mensurar os ganhos de bem estar da inovação tecnológica, com foco na inovação mais importante da indústria automobilística brasileira nas últimas décadas: os chamados carros *flex-fuel*, capazes de operar usando vários tipos de combustível. A fim de realizar esta tarefa, inicialmente foi realizada uma revisão da literatura, tanto acerca da evolução da tecnologia quanto sobre a avaliação de novos produtos. Na parte empírica, uma estimação econométrica de uma relação de demanda por meio do Modelo Logit de Coeficientes Aleatórios levou a uma estimativa de ganhos para o consumidor, de acordo com a hipótese de concorrência perfeita, de aproximadamente R$ 1200 por família, e de por volta de 1000 reais sob a premissa de competição com produtos diferenciados.

JEL Codes: C51, D12, D43, D60, L13, O47
Keywords: Demand, Valuation of New Goods.

Palavras-Chave: Demanda, Avaliação de Novos Produtos
Área 8: Economia Industrial e da Tecnologia

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1 Introduction

One of the most recent innovations of the Brazilian Automobile Industry was the introdution of the so-called *flex fuel* cars, vehicles capable of funcion using different fuel types. The first one was launched in 2003 by Volkwagen, with an electronic fuel injection system developed by Bosch, consisting of a sensor that automatically detected the fuel composition and adjusted the engine accordingly.

This engine was the culmination of a process that began in the last decade of the twentieth century, in the footsteps of a government program dating from the seventies: the Pro-Alcohol. This development clearly benefitted the users, widening their choice set, enabling them to adjust precisely both the desired performance as well as the fuel expenditure. Since the fuel consumption is different for a car running either on gasoline or ethanol, the choice of gasoline as fuel is preferred when the price of ethanol fuel is higher than 70% of the gasoline price.

Undoubtedly relevant, this phenomenon invites further study and provides the motivation for the present paper. It is also an application of techniques for the valuation of the benefits from innovation. In order to do so, this paper is structured on six sections, the first one being this introduction. The next section presents a short description on the history of the technology and sales of flex-fuel cars in Brazil, followed by a survey of the literature on the welfare effects of new goods. The welfare calculations will be carried out on the fifth section, and the sixth concludes.

2 Multi-fuel automobiles: history

The first experiments on cars moved by energy derived from ethanol in Brazil were carried out at about one hundred years ago, with the first experimental vehicles built in 1902. In 1930, the University of São Paulo developed a version of the famous Ford Model T moved by *cachaça*, a typical Brazilian beverage made of distilled sugar cane. In 1953, Urbano Ernesto Stumpf began the adaptation of a four stroke engine to be moved by ethanol, at the Air Force Tecnology Institute labs, in São José dos Campos.

However, the continuous and organized research on ethanol as an alternative fuel source began with a government program in the seventies, enacted as a response to both Oil World Crises (in 1973 and 1979). Before then, the prevailing oil prices did not make the large scale usage of other fuel types worthwhile. After the First Oil Shock in 1973, the interest on alternative energy sources was renewed, with many countries looking for solutions in accordance to their characteristics. In the Brazilian case, the expenditures on crude oil imports increased from US$600 million in 1973 to US$2,5 billion in 1974, affecting the trade balance and increasing both external debt and inflation, which increased from 15,5% per annum in 1973 to 34,5% in 1974.

According to Bertelli (2005), the general Ernersto Geisel, at that time the future president of Brazil, worried with the effects of the Oil Crisis on the goals of the Second National Development Plan, as well as on inflation control, GDP growth and external balance, asked the then Director of Petrobras and future Minister of Mining and Energy, Shigeaki Ueki, for private sector input on this question.

In response to this demand, the Association of Distributers of Liquefied Gas (Associgas) was transformed into a forum on this topic, coordenated by the entrepreneur Lamartine Navarro Jr, with colaboration of engineer Cícero Junqueira Franco, great specialist in technology for ethanol production, together with academics and sugar mill owners from São Paulo.

The results of the were in a paper intitled "Photosynthesis as energy source?" presented to the National Oil Council on March 1974, which was the starting point of the Alcohol National Program (*ProAlcool*). This study was a compromise between the wiews of the Sugar and Alcohol Institute[1] on ethanol being produced in independent distilling facilities and those of Copersucar, which favored the employment of idle capacity of the distilling facilities of sugar processing units.

According to Bertelli (2005), on July 1975, the president Ernesto Geisel, during a visit to Air Force Tecnology Institute, in São José dos Campos, had shown interest in studies developed by Professor Urbano Ernesto Stumpf on adapting motors to use a mix of gasoline and ethanol, as well as on converting them to using ethanol only. According to Professor Stumpf, the president´s impression on the usage of ethanol as fuel was decisive to the Federal Governement support of *ProAlcool*. At that time, Brazil had a well-developed sugar processing sector, adequate soil and climate, available rural workforce, experience in ethanol production, being a large producer and exporter, and the sector had idle capacity that could be reduced with the production of ethanol fuel.

After studies and debates, the Federal Government established the *ProAlcool* on november 14th, 1975 (Decree n.76.593). According to this decree, the ethanol production from sugar cane, cassava or other sources should be supported by increasing the supply of available inputs, increasing storage capacity, modernizing and enlarging existing facilities, and setting up of new ones either connected to existing ones or entirely autonomous. From that moment on, the history of the *ProAlcool* project can be classified into five stages:

- **Initial Stage:** from 1975 to 1979. Characterized by a concerted effort in ethanol production to be mixed with gasoline. The production grew from 600 million litres (crop 1975-1976) to 3,4 billion litres (crop 1979-1980).

- **Affirmative Stage:** 1980 to 1986. After the tripling of oil prices in 1979 (Second Oil Shock), the government accelerated the setting up of the program, creating bodies such as the National Council for Ethanol (CNAL) and National Executive Comission for Ethanol (CENAL). The ethanol production reached 12,3 bilions of liters at crop 1986-1987, surpassing by 15% the established goals. The share of vehicles using ethanol in total auto production increased from 0,46% in 1979 to 26.8% in 1980, reaching 76.1% in 1986.

- **Stagnation Stage:** 1986 to 1995. In 1986, the international oil market changes significantly, the prices falling from US$30/40 per barrel to about US$12/20. The so-called "Counter Oil Shock", kept in check the substitution of fossil fuels, as well as other energy efficiency initiatives

[1] The Sugar and Alcohol Institute (*Instituto do Açúcar e do Álcool*) was a government body entrusted to oversee the sugar industry, including sugar mills. Since the Brazilian ethanol is based on sugar cane, and is produced by the same facilities, its influence on this policy was significant.

around the world. In Brazil, the effect of this shock was felt after 1988, together with the crisis in public finance, reducing the subsidies to the alternate energy programs. Thus, ethanol supply could not keep up with the growth in demand.

This combination of disincentives to supply and demand incentives by market forces and government intervention, caused the supply crisis of 1989-90 crop, putting owners of ethanol fueled cars at risk of being unable to find fuel. This supply crisis affected the credibility of *ProAlcool*, which, together with the decrease in the amount of government subsidies, caused a reduction in sales of cars moved by ethanol.

Together with this tendency, the auto industry began to standardize engines and models worldwide. In the begining of the 90´s, Brazil liberalized car imports (which ran on gasoline and diesel fuel), and introduced incentives to the production of low horsepower engines, which were designed to run on gasoline.

This risk to car owners was reduced with the introduction of a mixture of gasoline and ethanol, the so-called MEG mixture, with approximately the same performance as the ethanol fuel. This increased the imports of both ethanol and methanol fuels (which surpassed 1 billion litres between 1989 and 1995) to garantee the supply of fuels.

- **Redefinition Stage:** 1995 to 2000. The market of ethanol fuel was completely liberalized, in the production, distribution and resale stages, with prices determined by market forces. In the period between 1998 and 2000, according to ANFAVEA, the growth rate of production of vehicles moved by ethanol was constant around 1% per annum.
- **Current Stage:** since 2000. After more than 30 years since the *ProAlcool* decree, the country is undergoing a new boom in this sector. The areas dedicated to sugar cane production now stretch beyond traditional areas, such as the countryside of São Paulo state and of northeastern region of the country, invading the central plateau of Brazil. Differently from previous stages, this is not controlled by the state, but by the result of market forces.

The biofuel technology, to be described in depth on the following section, gave new impulse to ethanol consumption in Brazil. The so-called *flex-fuel* cars, which can be fueled by either ethanol, gasoline and a combination of both, were introduced in the begining of 2003. This technology and its widespread adption throughout the world have provoked important changes in the attitudes of Brazilian auto industry, as well as other agents in this market. On the following section the technical aspects of the solution will be described.

2.1 Biofuel Engines: Technology

Given the governmental initiatives on new fuels mentioned on the previous section, Brazil was a fertile testing ground, both for the auto industry and the academic community. Because of these incentives, the country became a reference center in the subject of mixing fuels, putting in place a remarkable technology, the flex-fuel car. This technology freed consumers from the exclusive dependence of oil or ethanol producers, allowing ethanol to compete directly with gasoline and making it possible a gradual transition from non-renewable fuels.

According to Teixeira (2005), the history of flex-fuel engines began in the mid 80´s, in the USA (and specially in California), from government pressure for the introduction of autos moved by other fuel types. The government agency CARB (California Air Resources Board) established criteria for preferential tax treatment conditional to the creation of a car fleet using methanol and gasoline. The U. S. Government also began the required improvements in the infra-structure for ethanol distribution.

These factors provided the stimulus to the automakers to develop a fuel management system for car engines. The studies of the North American branch of Robert Bosch for the usage of methanol and of ethanol served as a basis to the development of flex-fuel motor concept. Without any direct involvement in the USA government incentives, the Robert Bosch Company, in its California labs has begun researching for a prototype of this hybrid system (Teixeira, 2005, p. 7). The Company has also determined, in a 1994 paper presented at the Society of Automotive Engineers, the two main technical approaches to a flex fuel car.

In the first one, an infrared ethanol sensor detects the ethanol concentration in the fuel before its combustion, releasing adequate power to the spark plug to carry out the fuel combustion. The sensor has a set of routines which map the fuel composition to the required power for the combustion to be carried out efficiently. Teixeira (2005) reports the American car fleet running on ethanol until that year still uses this technological solution. In Brazil, on the other hand, this technology is not used, since the cost of this sensor is so high only high powered (and expensive) cars could offer this option.

In the second one, another type of sensor examines the oxygen content on the exhaust fumes for the correct mixing of air and fuel required for an effective fuel burn. This technology was widely adopted in Brazil because of two factors. The first one was the high price of the fuel sensor, which pushed for a technical solution which eliminated the need for it, and such solution was found by Magnetti Marelli. And the second one was that, in Brazil, the usage of sensors for examining the fuel content was already in place, considering the introduction of the MEG mixture mentioned on the previous section, even for gasoline fueled cars. After Magnetti Marelli presented its solution, Bosch also presented a technology that did not rely on the fuel sensor, in 1998.

Regardless of the technical solution adopted, the launch of flex-fuel cars also required some other changes on the metal alloys used on the engine. The chains of carbon atoms which compose ethanol are highly corrosive, and the gasoline has a higher burn velocity and is more reactive under lower temperatures. Furthermore, in Brazil, about 7% of both fuel types are composed of water, which compounds the problems to be faced.

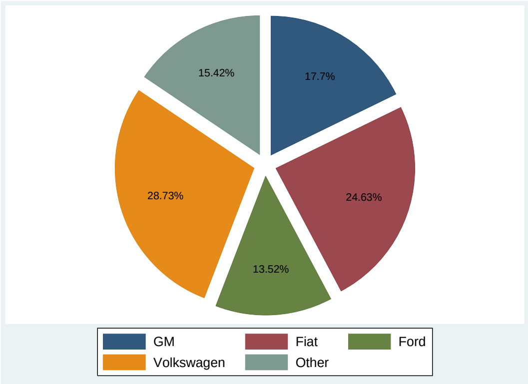
All these technical problems were already solved by the end of the last decade of the twentieth century; however, at that time none of the larger automakers indicated any interest on the technology. Even the vehicles that had to be used as prototypes had to be acquired independently by Magnetti Marelli or Bosch. The conclusions of these studies did not affect the behavior of Brazilian auto industry for more than 10 years. Only in 2002, after a classification of the Brazilian Federal

Government of flex fuel cars in the same category of ethanol only vehicles, enabling them to receive the same tax treatment, the flex fuel car was launched in 2003. The sales of flex fuel cars have increased steadily, as the next section shows.

3 Flex Fuel Sales: Effects on Market

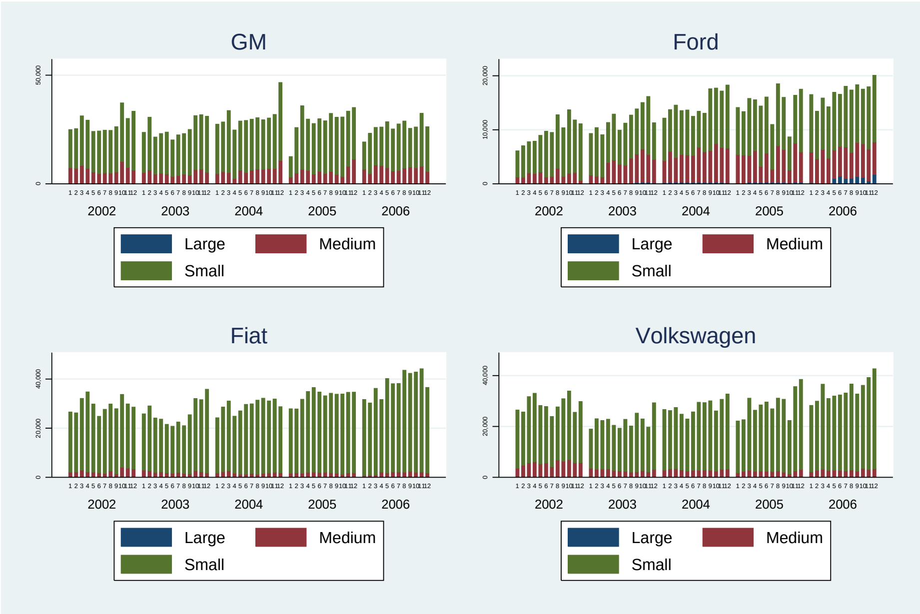
In order to understand the effects from the introduction of the *flex-fuel* car on the Brazilian car market, we must start by providing some information on the situation of the market during the period to be analyzed. By the end of 2006 there were 17 car makers offering their products, of which four of them had the biggest sales volume: Volkswagen, Fiat, General Motors and Ford. The following figure presents the breakdown of sales of these brands:

Figure 1: Market Share (units sold)



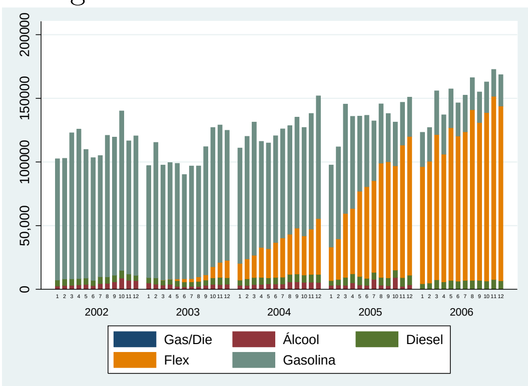
These automakers have specialized on sales of small and, to a lesser extent, medium cars. From January 2002 and December 2006, the only automaker which still had some relevant share of large cars was Ford. All other three automakers have focused their sales on small and medium cars.

Figure 2: Car Size by Automaker



After its introduction, flex fuel car sales increased steadily, as the following figure shows:

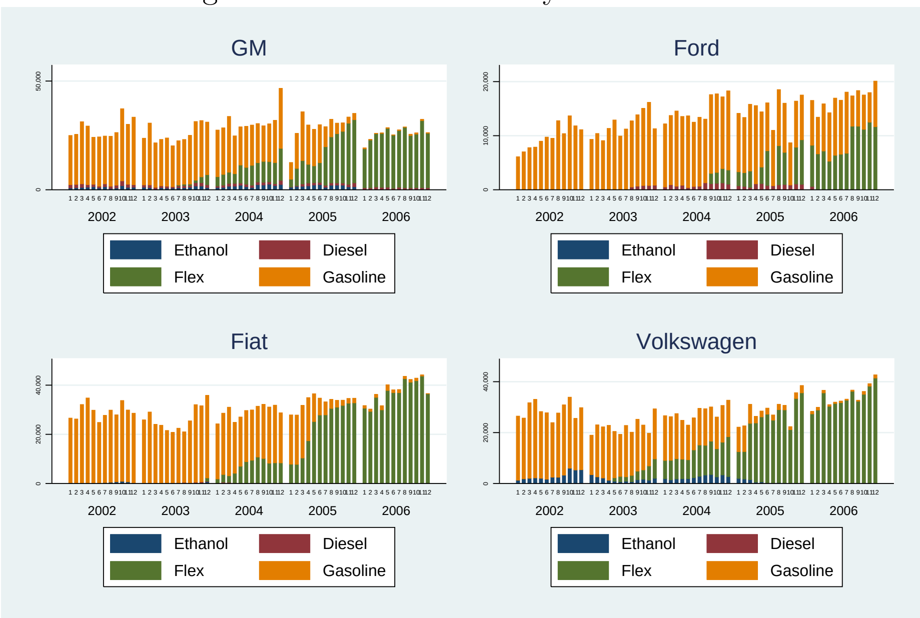
Figure 3: Sales of Flex-Fuel Cars



The strategy followed by these four automakers for the launch of *flex fuel* cars was quite similar, focused on the introduction of *flex fuel* versions of previously offered cars, specially small ones. After the Government initiative of classifying the *flex-fuel* cars in the same tax category of ethanol only vehicles, the most important automakers in Brazil – Ford, General Motors, Volkswagen and Fiat – began to associate with the companies which developed the technology. Ford and Fiat use the technology developed by Magnetti Marelli, General Motors is supplied by Bosch and Volkswagen operates with both companies. In 2003, Magnetti Marelli unveils two prototypes ready for production – Polo (of Volkswagen) and Vectra (of GM). However, the start of commercial production of *flex-fuel* cars was in april 2003, with the Gol Total Flex 1.6, as part of the fiftieth aniversary of the Brazilian operations of Volkswagen.

Only at the end of the period, at about the second half of 2006, some automakers have completed their transition towards offering a wide range of flex fuel car models, as the following figure shows. Only Ford set itself apart having a sizeable share of sales of Gasoline only cars.

Figure 4: Flex-Fuel Sales by manufacturer



Some points must be stressed from these picture. First of all, the share of *flex fuel* cars has increased steadily in the years following the initial presentation of the technology, corresponding to a great majority of auto sales in 2006. As for the timing of the introduction of *flex fuel* cars, by the end of 2003 three of the big four automakers have already started selling car models using the tecnology. Only Ford waited until the second half of 2004 to begin selling *flex fuel* cars. Undoubtedly, this increase comes as a result of this technology bringing forward an increase in consumer welfare, among other factors. In the next section, the formal methodology for measuring welfare gains is presented.

4 Welfare Gains of New Goods.

The literature on the valuation of new goods has a long history, beginning with the studies of Hicks (1940) on the construction of price indexes to evaluate the effects of food rationing and the introduction of new goods. The most important concept to this analysis is the virtual price, the hypothetical price that would equate the consumption rationed to the quantity consumed without rationing. Expanding on this concept, Hicks develops the virtual price required to the valuation of a new product, which will be the one that makes the quantity demanded equal zero. After finding this price, it is be possible to quantify the welfare gains of a new product, by integrating the demand curve between the observed price and the virtual price.

This concept was also applied in a discrete choice setting where, if in face of J alternatives, a consumer chooses only the one that gives him the greatest utility derived from the consumption of this alternative. In this setting, the conditional[2] indirect utility the consumer i derives from alternative j, with features indexed by θ, can be represent by $u_{ij}(\theta)$. The unconditional indirect utility of this product set is called $V_i^J(\theta)$, and is equal to:

$$V_i^J(\theta) = \max_{j \in J} u_{ij}(\theta)$$

This formulation makes it possible to understand, in a simple way, how the virtual price can be used to compute the welfare gains from new products. Considering the vector θ to be composed of just two elements, $\mathbf{P}^1$ – the price vector of all goods – and y_i, the consumer income, the virtual price obtains from a change of the price vector $\mathbf{P}^1$to a new value $\mathbf{P}^2$, implying no consumer purchases of the product. After this virtual price, $\mathbf{P}^2$, is found, it is easy to calculate the welfare gains from the intoduction of this good as the Equivalent Variation, as shown by McFadden (1981):

$$EV_i = \frac{V_i(\mathbf{P}^2, y_i) - V_i(\mathbf{P}^1, y_i)}{\alpha_i}$$

In which the α_i would be the price effect on conditional indirect utility $\frac{\partial u_{ij}}{\partial p_j}$. If the consumers are identical with respect to the weighting they put on the different attributes, the α_i will be identical for all consumers, and so will be the Equivalent Variation. However, when it is not valid, this value will be different for every consumer, and a useful measure of welfare gain would be the mean Equivalent Variation, defined under the distribution of individual characteristics that might cause the weighting of characteristics to differ between consumers. Denoting the joint distribution of individual characteristics – both observed by the econometrician, denoted $\mathbf{z}$, and unobserved, which will be denoted $\mathbf{v}$ – as $P(\mathbf{z}, \mathbf{v})$, the Mean Equivalent Variation is the integral of EV_i under the distribution of individual characteristics:

$$\bar{EV} = \int EV_i dP^\star(\mathbf{z}, \mathbf{v}) \tag{1}$$

Hausman (1994) has noticed an additional concern with respect to the computation of the virtual price. Under imperfect competition, this virtual price will affect the price of other goods, not directly involved in the counterfactual analysis, since the prices are the result of an equilibrium in which a change in one price affects will be taken into account on the price setting of other products. Only if it is considered the products are supplied in perfect competition, these cross effects will be important factors on the final price vector under the counterfactual.

[2] Conditional on the choice of the alternative.

In order to fully understand the point, with strategic competition in prices (Nash-Bertrand), each firm maximizes its profits by taking into consideration the prices of all products it brings to the market. The demand by firm´s good j on market with J firms becomes:

$$Q_j = D(p_1, \cdots, p_J, Y, \gamma), j = 1, \cdots, J$$

Where γ represents a parameter vector and $p_1, \cdots, p_J$ a price vector analogous to the $\mathbf{P}$ discussed before. In this case, the firm's profits can be written as

$$\Pi_j = \sum_{j \in I} (p_j - CMg_j(W, \beta)) \times Q_j - F$$

With W representing cost side exogenous variables, β the coefficient vector of the cost function, and F fixed costs. An important point in the previous equation is the summation is taken with respect to the products belonging from the same firm, represented by the I set. Considering the firms compete in prices, the first order conditions for profit maximization imply for product j the following:

$$Q_j + \sum_{k \in I} (p_k - CMg_k) \times \frac{\partial Q_k}{\partial p_j} = 0$$

These first order conditions must hold for all products, differing only on the composition of the relevant I set, as products from different firms have their prices set considering different cross-price sensitivities. These first order conditions can also be expressed in matrix form, after defining two matrices which are central for the following analysis. The first one is called $\mathbf{S}$, wth typical element $S_{jr} = -\frac{\partial Q_r}{\partial p_j}, j, r = 1, \cdots, J$, and represents the negative of the demand sensitivity of the r-th good to the j-th price. The second one defines the ownership of each product is denoted $\mathbf{\Theta}$, with typical element as follows:

$$\Theta_{jr} = \begin{cases} 1, & \exists f : \{r, j\} \in I \\ 0 & c.c. \end{cases}$$

These matrices can be combined to yield the $\mathbf{\Omega}$ matrix, with typical element $\Omega_{jr} = \Theta_{jr} S_{jr}$, needed to represent in vector notation the system of first order conditions:

$$\mathbf{Q(P)} - \mathbf{\Omega}(\mathbf{P} - \mathbf{CMg}) = \mathbf{0} \tag{2}$$

With the $\mathbf{Q(P)}$, $\mathbf{P}$ and $\mathbf{CMg}$ vectors assembled from the vertical stacking of the individual quantities, prices and marginal costs, respectively. The solution of this system of equations in which the values of the $\mathbf{Q(P)}$ matrix of the goods to be analyzed are driven to zero are called the virtual prices. These prices take into account the effects these increases have on other goods' demands – represented by the Ω matrix in the (2) equation – and indicating all elements of the price vector are expecing to to be different from their initial values. Thus, assuming Nash-Bertrand behavior from the supply side, in order to compute the virtual price it is required the new price vector to be such the prices of the products to be analyzed lead to zero units demanded and the system of first order conditions (2) to be satisfied for all products in this market.

For either behavioral assumption for the suppliers, it is important to point out that a key element is the estimation of the Ω matrix, which requires estimates of the cross-price sentitivities in the S_{jr} matrix. On this paper, a Random Coefficient Logit Model, as in Berry, Levinsohn and Pakes (1995) will be used. The model begins with the following specification for the i consumers' utility from choosing the j brand in market t:

$$u_{ijt} = -\alpha_i p_{jt} + \mathbf{x_{jt}}\gamma_\mathbf{i} + \xi_j + \varepsilon_{ijt}$$

The most important difference from the models presented so far lies on the fact the utility function presented is indexed not only by j and t (brands and time period) but also by consumer i, with the marginal effect of a characteristic on the conditional indirect utility allowed to be different for each consumer[3]. Berry, Levinsohn and Pakes make the following assumption in order to recover these individual effects on the coefficients from aggregate data:

$$[\alpha_i, \gamma_\mathbf{i}] = [\alpha + \mathbf{z_i}\alpha_\mathbf{i}^\mathbf{o} + \mathbf{v_i}\alpha_\mathbf{i}^\mathbf{u}, \gamma + \mathbf{z_i}\gamma_\mathbf{i}^\mathbf{o} + \mathbf{v_i}\gamma_\mathbf{i}^\mathbf{u}]$$

In which the non-indexed coefficients represent the average marginal effects of the characteristics on the utility levels and the coefficients superscripted **o** and **u** denote the effects of observed individual characteristics – the $\mathbf{z_i}$ – and unobserved individual characteristics – the $\mathbf{v_i}$ – on the sensitivities of utility to the product attributes. This assumption implies the price sensitivity of the conditional indirect utility may vary with respect to observed and unobserved individual characteristics. Reorganizing the utility specification, we can express it as:

$$\begin{aligned} u_{ijt} &= -\alpha p_{jt} + \mathbf{x_{jt}}\gamma + p_j\mathbf{z_i}\alpha_\mathbf{i}^\mathbf{o} + p_j\mathbf{v_i}\alpha_\mathbf{i}^\mathbf{u} + \mathbf{x_{jt}}\mathbf{z_i}\gamma_\mathbf{i}^\mathbf{o} + \mathbf{x_{jt}}\mathbf{v_i}\gamma_\mathbf{i}^\mathbf{u} + \varepsilon_{ijt} \\ &= \delta_{it} + p_j\mathbf{z_i}\alpha_\mathbf{i}^\mathbf{o} + p_j\mathbf{v_i}\alpha_\mathbf{i}^\mathbf{u} + \mathbf{x_{jt}}\mathbf{z_i}\gamma_\mathbf{i}^\mathbf{o} + \mathbf{x_{jt}}\mathbf{v_i}\gamma_\mathbf{i}^\mathbf{u} + \varepsilon_{ijt} \\ \delta_{it} &= \mathbf{x_{jt}}\gamma - \alpha p_{jt} \end{aligned}$$

The δ_{it} above is analogous to the deterministic part of the u_{ijt} utility for the logit and nested logit specifications presented before. In order to derive market shares, a distribution for the ε_{ijt} terms must be assumed, usually the extreme value I distribution, allowing the market shares to be represented as:

$$s_{jt} = \int \frac{\exp[-\alpha_i p_{jt} + \mathbf{x_{jt}}\gamma_\mathbf{i} + p_j\mathbf{z_i}\alpha_\mathbf{i}^\mathbf{o} + p_j\mathbf{v_i}\alpha_\mathbf{i}^\mathbf{u} + \mathbf{x_{jt}}\mathbf{z_i}\gamma_\mathbf{i}^\mathbf{o} + \mathbf{x_{jt}}\mathbf{v_i}\gamma_\mathbf{i}^\mathbf{u}]}{1 + \sum_j \exp[-\alpha_i p_{jt} + \mathbf{x_{jt}}\gamma_\mathbf{i} + p_j\mathbf{z_i}\alpha_\mathbf{i}^\mathbf{o} + p_j\mathbf{v_i}\alpha_\mathbf{i}^\mathbf{u} + \mathbf{x_{jt}}\mathbf{z_i}\gamma_\mathbf{i}^\mathbf{o} + \mathbf{x_{jt}}\mathbf{v_i}\gamma_\mathbf{i}^\mathbf{u}]} d\hat{P}^*(\mathbf{Z})dP(\mathbf{V})$$

Since this approach is adequate for situations where data on individual characteristics is not available, usually the Method of Simulated Moments is used, since closed form solutions are not

[3]The term ξ_j represents the unobserved mean across consumers of unobserved component of utility. Since the main role of this term is to provide an economic justification for the Method of Moments present in Berry, Levinsohn and Pakes paper, it will not be represented in the following demonstration, in order to simplify the notation.

available to integrate the market shares. The substitution patterns are derived as follows:

$$S_{jr} = \begin{cases} \int \alpha_i s_{ijt} s_{irt} d\hat{P}^\star(\mathbf{Z}) dP^\star(\mathbf{V}) & if\, j \neq r \\ -\int \alpha_i s_{ijt}(1 - s_{ijt}) d\hat{P}^\star(\mathbf{Z}) dP^\star(\mathbf{V}) & else \end{cases}$$

In which the $\hat{P}^\star(\mathbf{Z})$ represents the population distribution for the observed consumer characteristic, and $P^\star(\mathbf{V})$ the population distribution for the unobserved consumer characteristic. The mean Equivalent Variation must also be computed by integration by simulation of the following:

$$\bar{EV} = \int \frac{\ln(V_i(\mathbf{P}^2)) - \ln(V_i(\mathbf{P}^1))}{\alpha_i} d\hat{P}^\star(\mathbf{Z}) dP^\star(\mathbf{V})$$

In which V_i is, as discussed before, the unconditional indirect utility, equal to $\max_j u_{ijt}$. These models will provide the source for the econometric analysis on the following section.

5 Econometric Analysis

The starting point in the econometric analysis is to describe the dataset used by the study to evaluate the welfare effects of the introduction of flex-fuel cars. It was assembled from two different databases, one from ANFAVEA[4] on domestic sales of cars, and another on prices from *O Estado de São Paulo*, a newspaper which collects weekly data on new cars' prices. Since the matching of these two databases was not perfect – the data was far more finely dissaggregated for prices than for quantities – the median price of all versions of a given model for which quantity data was available was matched to the information on sales. As for the characteristics of the automobiles used, the following information on the median model of each type of car was collected:

- Engine Displacement in Cubic Centimeters
- Number of valves
- Number of cylinders
- Four Wheel Drive

The last one is a dummy variable, taking the value of zero if the median model is not available with four wheel drive and one otherwise. The descriptive statistics are presented on the Appendix, as well as the monthly averages of all variables. The following table also presents the evolution of the sales weighted averages of these variables, as well as sales and prices:

[4]Brazilian Association of Car Manufacturers

Table 1: Year by Year Sales Weighted Averages

Year	Price	Sales	Valves	Cylinders	HP-CC	4WD
2002	36299.41	6463.45	10.55	4.01	1.33	0.02
2003	34146.38	5351.11	9.55	4.00	1.41	0.02
2004	38988.60	4667.57	8.97	4.00	1.41	0.03
2005	42432.54	5520.25	8.93	4.00	1.40	0.03
2006	42715.53	6588.78	8.81	4.02	1.41	0.02
Overall	39244.90	5739.22	9.32	4.01	1.39	0.02

These averages indicate some interesting trends. The average price of a car model display a marked upward trend, from about 36 thousand Reais in 2002 to about 42.7 thousand in 2006. This price increase in real terms (all nominal variables are expressed in Reais of constant purchasing power of 2006) was associated with an increase in average sales – both overall, as seen on Section 3, as well as per model. The average engine power is about 1.4 thousand cubic centimeters, indicating the preference of Brazilian consumers for low power engines. The next two tables show the percentiles of the price and sales distributions, as well as the corresponding models.

Table 2: Distribution of prices

Model	Yr-Mo	Pctile	Price
KOMBI ethanol	2003m10	1	35,124
POLO flex	2006m6	2	47,147
GOLF gasoline	2006m5	3	66,683
LAGUNA gasoline	2005m7	4	127,217
CLK gasoline	2003m7	5	1,054,210

Table 3: Sales

Model	Yr-Mo	Pctile	Sales
147 gasoline	2002m7	1	17
MASTER diesel	2003m5	2	89
BLAZER gasoline	2004m12	3	596
SIENA gasoline	2004m9	4	1,524
GOL gasoline	2002m4	5	20,836

These tables help us to characterize more fully the distribution, as well as associating some models with the price and sales distributions. The most expensive car is from Mercedes-Benz, a CLK model, costing more than 1 million Reais, and the most expensive between the first quintile is the VW Kombi flex-fuel, at about 35 thousand reais. As for sales, the largest number of sales recorded is over 20 thousand sales, of the VW Gol, and the largest sales of the first quintile is of Alfa Romeo 147.

Another assumption made pertains to the size of the potential market for Brazilian automobiles. In order to do that, information from the annual research on households (named as PNAD from its Portuguese acronym) was collected on the number of households with family income over 3,000 Reais (values of 2006). This number is presented on the following table:

Table 4: Number of Families with income over 3,000 Reais

Year	Number
2002	5,596,089
2003	6,742,787
2004	5,764,678
2005	6,145,187
2006	6,507,141

Implicitly it is assumed the potential market for automobiles corresponds to one car per year for all families with combined income over 3,000 Reais[5]. The next section presents the econometric results. Besides the demand equation, it will also be presented an Marginal Cost equation, whose left-hand side was derived from reorganizing the first order conditions on equation (2) as follows:

$$\mathbf{CMg} = \mathbf{P} - \Omega^{-1}\mathbf{Q}(\mathbf{P}) \tag{3}$$

Leading to a linear Marginal Cost equation similar to (3), as follows:

$$\mathbf{CMg} = \mathbf{P} - \boldsymbol{\Omega}^{-1}\mathbf{Q} = \mathbf{x}\phi + u \tag{4}$$

In which the $\mathbf{x}$ represent the model characteristics, the ϕ a vector of parameters and u the econometric error term. The equations were estimated sequentially, as in Verboven (1994 and 1996), and Fiuza (2002), because mis-specification in the supply equation can bias the results in the demand equation, and this risk outweighs the efficiency benefits derived from the joint estimation of both equations.

Before we present the results, the idenfication strategy must be outlined. In order to face the simultaneity bias derived from the endogeneity of the price variable, as well as the logs of the conditional market share, were the summations of the characteristics of models, either produced by the same firm or all firms. The motivation for this choice resides on the following reasoning: the characteristics of other models are supposed to be correlated to the demand of the model j, but are not correlated to the production cost of model j. Thus, they are valid instruments[6]. The interactions

[5]That is, under 10% of the average price of a car model.

[6]Berry (1993 and 1995) use this reasoning.

between the instruments are also used in the estimation. Before the results are presented, an important point must be addressed concerning the validity of the instruments. Given the inputting process required to merge the price dataset with the quantity dataset above, the traditional identification strategy might not be valid. This issue of weak instruments will also be faced on the next section.

5.1 Econometric Results

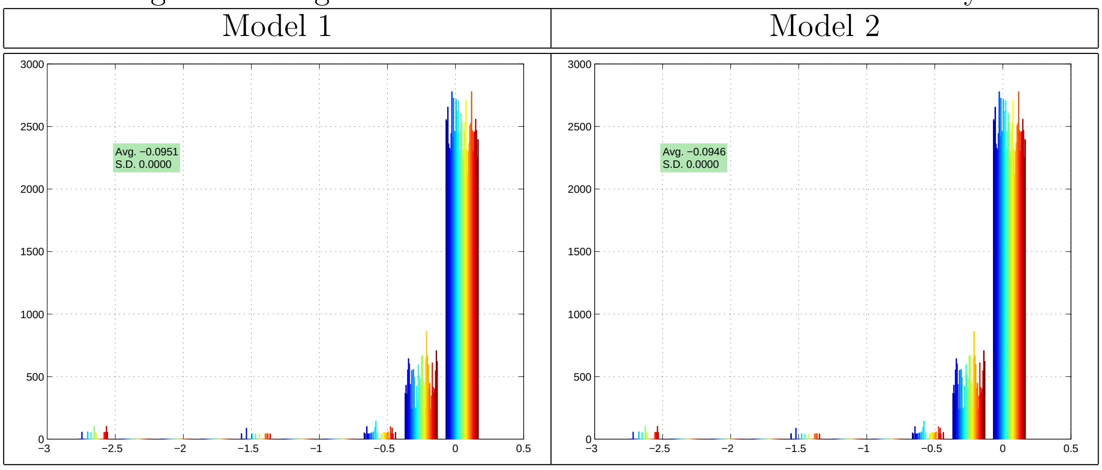
The last demand model to be estimated is similar to the Berry, Levinsohn and Pakes (1995) model. The conditional indirect utility assumed here is of the following form:

$$u_{ijt} = -\alpha p_{jt} + \mathbf{x_{jt}}\gamma + p_j \mathbf{z_i} \alpha_\mathbf{i}^\mathbf{o} + p_j \mathbf{v_i} \alpha_\mathbf{i}^\mathbf{u} + \mathbf{x_{jt}} \mathbf{z_i} \gamma_\mathbf{i}^\mathbf{o} + \mathbf{x_{jt}} \mathbf{v_i} \gamma_\mathbf{i}^\mathbf{u} + \varepsilon_{ijt}$$

In which the $\mathbf{x_{jt}}$ – the vector of observable characteristics – is composed of the number of valves on the engine, the engine power in thousands of cubic centimeters and a constant. As for the $\mathbf{z_i}$, the individual characteristics, they are the age of family head, the number of family members, the family income and the family income squared[7]. For each time period and model, there were 40 draws from the empirical distribution of these variables. Finally, the $\mathbf{v_i}$, the individual idiosyncratic unobserved characteristics, are drawn from a normal distribution with mean zero and standard deviation 0.1. Two models are estimated, one in which both income level and income squared are interacted with prices, and one in which only price squared is. The results for both models are presented on the next table.

Despite the fact some of $\alpha_\mathbf{i}^\mathbf{o}$, $\gamma_\mathbf{i}^\mathbf{o}$ and $\gamma_\mathbf{i}^\mathbf{u}$ are very imprecisely estimated, the α coefficient is very precisely estimated, indicating a own price sensitivity higher than the one implied by even the nested logit model. The following figure displays the sensitivity of the conditional indirect utility to price for all sampled individuals, as well as the overall mean and standard deviation.

Figure 5: Marginal Price Effect on Conditional Indirect Utility



[7]All demographics are drawn from the PNAD (*Pesquisa Nacional por Amostragem de Domicílios*), or National Household Sample Survey, from the Brazilian Statistical Office.

Table 5: BLP Estimates

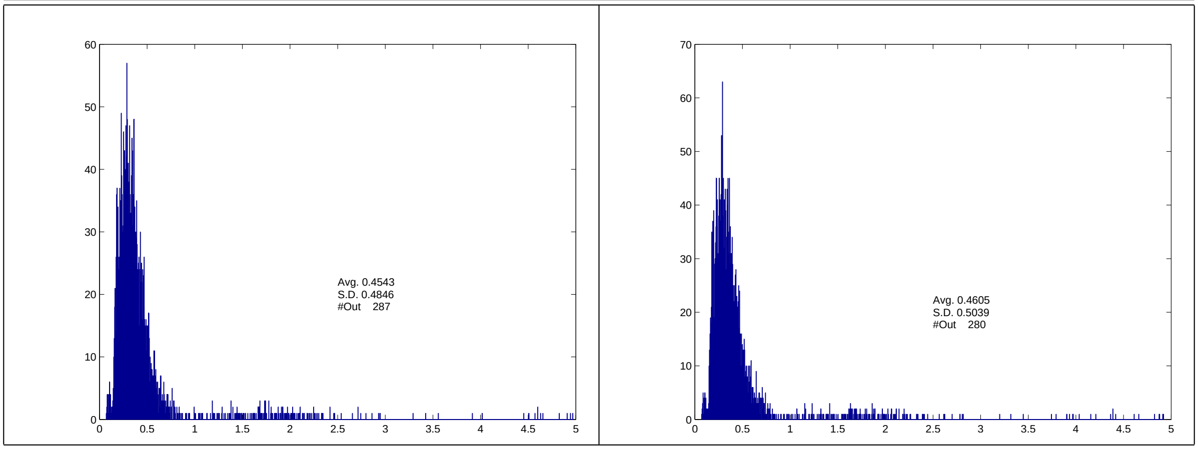
Coefficients		Model 1	Model 2	Coefficients		Model 1	Model 2
Mean	Constant	7.5288	-40.892	Observed Attributes	Constant * Age	8.72E-07	2.32E-06
(α,γ)		(2.38E-14)	(1.84E-13)	(α^o,γ^o)		(1.38E-05)	(1.64E-05)
	Price in BRL 1000	-0.05727	-0.05727		Price * Age	-4.20E-09	-5.26E-09
		(6.20E-05)	(8.92E-05)			(0.001253)	(0.001822)
	Number of Valves	-0.91108	-0.27389		Nr. Of Valves * Age	4.80E-09	-1.58E-08
		(2.38E-14)	(1.84E-13)			(0.000131)	(0.000144)
	Engine Displacement	-1.4166	23.608		Eng. Displ. * Age	1.45E-06	1.58E-06
		(1.80E-15)	(1.06E-15)			(2.86E-05)	(4.23E-05)
Unobserved Attributes	Constant	0.003157	0.001793		Price * HABS	2.65E-09	4.75E-10
(α^u,γ^u)		(2.38E-08)	(6.72E-08)			(1.99E-05)	(1.78E-05)
	Price in BRL 1000	3.59E-07	-2.69E-06		Constant * INCM	-3.10E-09	-4.20E-09
		(1.01E-06)	(3.59E-06)			(0.00072)	(0.000777)
	Number of Valves	-2.75E-05	-8.76E-06		Price * INCM		7.80E-10
		(3.68E-07)	(1.23E-07)				(1.71E-05)
	Engine Displacement	-0.00029	-0.00075		Number of Valves * INCM	-5.56E-10	-5.71E-12
		(3.18E-07)	(2.66E-07)			(3.85E-05)	(3.76E-05)
					Engine Displacement *INCM	-3.71E-13	1.45E-12
						(0.000491)	(0.000555)
					Price * (INCMSQ)	-5.76E-09	-5.70E-09
						(9.49E-10)	(1.75E-09)

OBS: Standard Errors in Parentheses

As a further check on the plausibility of the estimates, the number of economically meaningful elasticities was also computed, totalling 2555 (2556 for Model 2). These sentitivities also indicate a pattern for the implied markups at about 40% over marginal cost, as indicated below:

Figure 6: Implied Markups

Model 1	Model 2



From these implied markups, it can also be computed the marginal cost equation, on the following table.

Table 6: Marginal Cost Equation - Model 1

	OLS	**IV**	**LIML**	**FULLER**
Constant	274.7536	-25.8814	32.8110	33.1804
	(0.8073)	(-0.0390)	(171.1932)	(173.3844)
Number of Valves	-0.9917	0.6334	-0.1349	-0.1357
	(-0.4128)	(0.1841)	(-136.9945)	(-137.9025)
Number of Cylinders	32.1503	58.2797	61.7616	61.7015
	(0.6175)	(0.4202)	(1537.4470)	(1539.1236)
Engine	9.0088	26.3090	22.0730	22.0694
	(0.5474)	(1.1605)	(3390.8207)	(3392.8591)
Log(Price Index)	-64.7425	-38.4652	-48.1397	-48.1595
	(-1.4133)	(-0.6112)	(-2671.1960)	(-2673.0875)

OBS: Asymptotic t Statistics in Parentheses. LIML and FULLER t-stats computed using Bekker (1994) Standard Errors.

Table 7: Marginal Cost Equation - Model 2

	OLS	**IV**	**LIML**	**FULLER**
Constant	65.0525	-350.9673	-304.0295	-303.2544
	(0.3324)	(-0.9179)	(-907.2487)	(-906.3220)
Number of Valves	-0.1467	-0.7270	-1.0755	-1.0753
	(-0.1062)	(-0.3671)	(-627.8654)	(-628.0055)
Number of Cylinders	27.1526	103.0667	103.9952	103.8216
	(0.9068)	(1.2911)	(1477.6061)	(1478.1973)
Engine	18.4902	22.7274	20.4763	20.4863
	(1.9536)	(1.7417)	(1805.9705)	(1808.2375)
Log(Price Index)	-29.5247	-10.3857	-17.6700	-17.6868
	(-1.1208)	(-0.2867)	(-563.7214)	(-564.4223)

OBS: Asymptotic t Statistics in Parentheses. LIML and FULLER t-stats computed using Bekker (1994) Standard Errors.

These results will be used to calculate a mesaure of welfare gains for the consumers from the introduction of the flex-fuel car, on the next section.

5.2 Welfare Calculations: Results

In this section, the results of welfare calculations – defined as the difference between the consumer surplus under the current prices and the consumer surplus under the counterfactual implied by the virtual prices – are presented. The virtual prices are derived under two different competition structures: (i) the perfect competition assumption, in which the virtual price was computed under the hypothesis the prices of other cars are held constant, and (ii) the Bertrand assumption, in which the companies are allowed to change the prices of their cars in response to the computation of the price increase required for the virtual price. Thus, the Bertrand assumption requires not only the virtual price vector be such as the quantity demanded of *flex-fuel* cars would be zero, as in assumption (i), but also it satisfies the first order condition presented in equation (2) discussed before.

The following table present the results for an specfic month (May 2005), as an illustration of the gains to be computed. For the BLP model, the welfare gains for the introduction of the flex fuel cars for are presented on the following table:

Table 8: Mean Welfare Gain – BLP Model

	Model 1	Model 2
Perfect Competition	1275.45	1252.30
Bertrand	1093.60	1073.32

The results point out to average welfare gains at about one thousand reais, being larger under the perfect competition assumption than under the Bertrand Competition assumption.

6 Concluding Remarks

This paper tried to measure the welfare gains from technological innovations, focusing on the most important technological breakthrough of Brazilian auto industry on the last decade: the so-called flex-fuel cars, able to operate using various types of fuel. In order to do that, initially a literature review was carried out, both on the evolution of the technolgy as well as on the valuation of new goods, stressing the differences in new goods valuation arising from different competitive assumptions on the price-setting behavior.

On the empirical part, an econometric estimation of a demand relation was carried out using the Generalized Method of Moments, using the Random Coefficient Logit Model of Berry, Levinsohn and Pakes (1995). Finally, the welfare gains were computed which led to a welfare estimate, for the perfect competition assumption, of about 1.2 thousand Reais per family, in the same period, and about one thousand for the perfect competition assumption.

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A Appendix

A.1 Descriptive Statistics

Table 9: Descriptive Statistics

	Price	**Valv.**	**Cyl.**	**CC**	**4X4**
Mean	46442.15	9.85	4.01	1.63	0.05
Std.Dev.	19411.36	3.38	0.16	0.50	0.21
Max.	168845.00	20.00	6.00	4.30	1.00
Min.	13173.00	8.00	0.00	1.00	0.00