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Un análisis de la estructura tecnológica de refinerías y licuadoras: cálculo de la función de costo de Leontief multiproducto y reserva de precios

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An Analysis of the Technological Structure of Refineries and Blenders: Estimation of the Leontief Multiproduct Cost Function and Reservation Prices

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Keywords

Leontief, cost function, bio-fuels, monopolistic competition, virtual prices, ethanol

JEL Code

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Abstract

The Leontief multiproduct flexible cost function aims to give an approach to the technology used by refineries and blenders. In general, this cost function satisfies rational behavior restrictions imposed by economic theory. The estimated marginal costs are incorporated in a monopolistic competition model to calculate the virtual prices of other products provided by refineries and blenders in the hypothetical situation in which reformulated gasoline is absent in fuel markets. I have found that conventional gasoline and other product prices are greater than those in the mentioned hypothetical case. This result reflects the fact that consumers are being charged with high prices in order to have available a fuel which satisfies the Environmental Protection Agency (EPA) regulations. Finally, when all the products become perfect substitutes, i.e. consumers are not interested in the quality of fuels, price differences tend to be negligibly small.

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Un análisis de la estructura tecnológica de refinerías y licuadoras: cálculo de la función de costo de Leontief multiproducto y reserva de precios

Resumen

La función de costos flexibles multiproducto de Leontief pretende una aproximación a la tecnología utilizada por las refinerías y batidoras. En general, esta función de costos satisface las restricciones de comportamiento racionales impuestas por la teoría económica. Los costos marginales estimados se incorporan en un modelo de competencia monopolística, para calcular los precios virtuales de los demás productos ofrecidos por las refinerías y batidoras en la situación hipotética en la que la gasolina esté ausente en los mercados de combustibles. Se ha encontrado que la gasolina convencional y otros precios de productos son mayores que en el caso hipotético mencionado. Este resultado refleja el hecho de que los consumidores están asumiendo la sobrecarga de precios altos, con el fin de tener un combustible disponible que se ajuste a las regulaciones de la Agencia de Protección Ambiental (EPA). Por último, cuando todos los productos se convierten en sustitutos perfectos, es decir, los consumidores no están interesados en la calidad de los combustibles, las diferencias de precios tienden a ser insignificantes.

Palabras clave

Leontief, función de costos, biocombustibles, competencia monopolística, precios virtuales, etanol

Uma análise da estrutura tecnológica de refinarias e liquidificadores: cálculo da função de custo de Leontief multiproduto e reserva de preços

Resumo

A função de custos flexíveis multiproduto de Leontief visa uma aproximação à tecnologia utilizada pelas refinarias e batedoras. Em geral, esta função de custos satisfaz as restrições de comportamento racionais impostas pela teoria econômica. Os custos marginais estimados se incorporam em um modelo de competência monopolística para calcular os preços virtuais dos rosou produtos oferecidos pelas refinarias e batedoras na situação hipotética na que a gasolina esteja ausente nos mercados de combustíveis. Chegou-se à conclusão de que a gasolina convencional e outros preços de produtos são maiores que no caso hipotético mencionado. Este resultado reflete o fato de que os consumidores estão assumindo a sobrecarga de preços altos, com o objetivo de ter um combustível disponível que se ajuste às regulações da Agência de Proteção Ambiental (EPA). Por último, quando todos os produtos se transformam em substitutos perfeitos, ou seja, os consumidores não estão interessados na qualidade dos combustíveis, as diferenças de preços tendem a ser insignificantes.

Palavras chave

Leontief, função de custos, biocombustíveis, competência monopolística, preços virtuais, etanol

Introduction

Increases in petroleum prices have affected the prices of its derived products. In addition, interest in issues related to the environment and energy security at a world-wide level has increased. All of these factors have contributed to the development of alternative fuel such as ethanol, biodiesel, and natural gas.

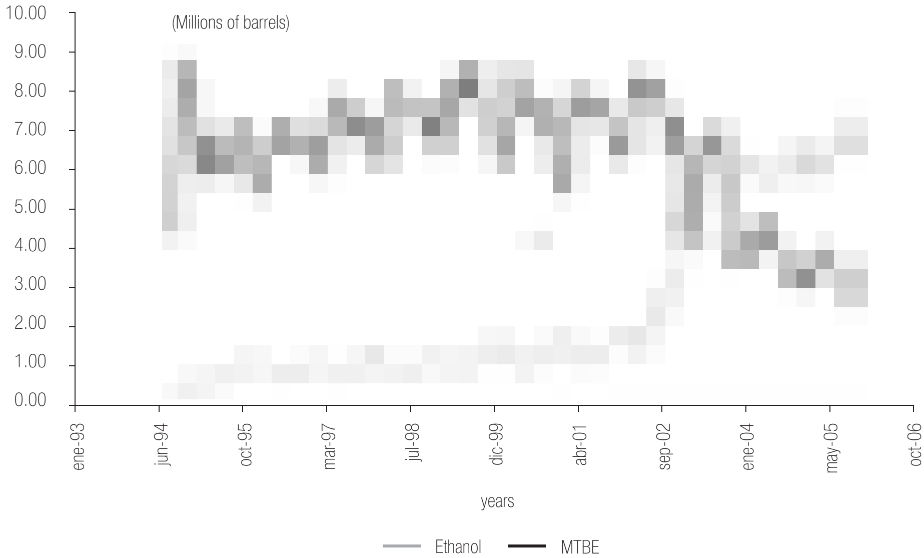
In the United States, specifically, there are two major renewable fuels that are being produced. Ethanol produced from grain, and biodiesel produced from vegetable oils and animal fats.

The production of ethanol fuel is mainly based on corn, with a minor amount of fuel ethanol produced from other feedstocks, including sorghum, cheese whey, and beverage waste. On the other hand, the production of biodiesel is based on different oils, including soybeans, canola, peanut, corn, cottonseed, and animal fats such as tallow, yellow grease, and lard.

The demand for ethanol and biodiesel in the United States is mostly mandated by federal and state legislations. Legislation, such as the Clean Air Act Amendments (CAAA) of 1990, the Energy Policy Act of 1992, and the Energy Conservation Reauthorization Act of 1998 allowed the growth of the renewable fuel industry during the 1990s. Recently, the Farm Security and Rural Investment Act of 2002, the American Jobs Creation Act of 2004, and the Energy Policy Act of 2005 have strengthened the development of these biofuels.

In particular, ethanol has been used as fuel in the U.S. since 1908. Efforts to sustain an U.S. ethanol program failed. Oil supply disruptions in the Middle East and environmental concerns over the use of lead as a gasoline octane booster renewed interest in ethanol in the late 1970s. In general, the demand of ethanol is determined by its two end uses, that is, as a conventional gasoline volume extender, and as an oxygenate. In the past, methyl tertiary butyl ether (MTBE) was the main oxygenate utilized by refineries. Ethanol and MTBE were considered substitutes for this end use, but MTBE is currently being phased out in some states due to its drawbacks. Figure 1 depicts this situation. We can observe that the demand of ethanol as a refinery input has risen noticeable in 2002, the year in which the state of California announced a ban on the use of MTBE.

Figure 1. Ethanol and MTBE as Refinery and Blenders Input

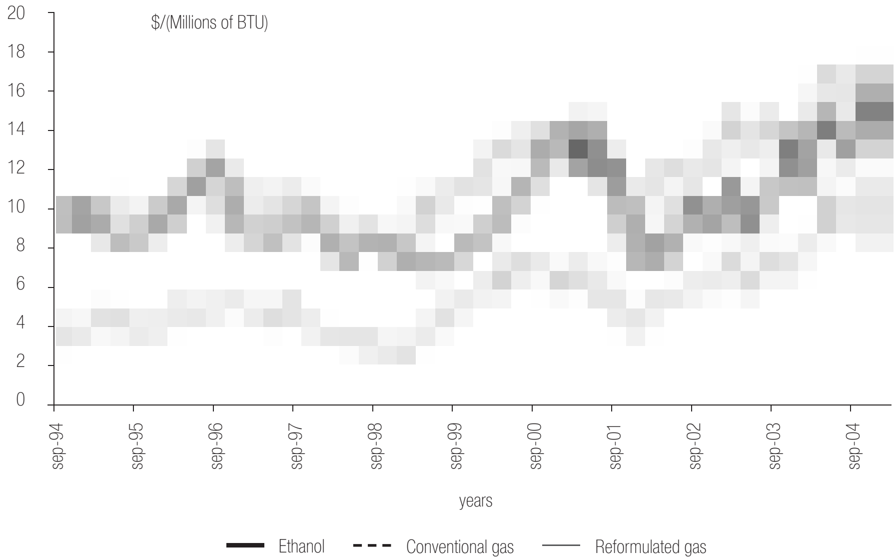


Source: Own elaboration.

The oxygen content requirement included in the federal and state policies and regulations has opened a market for ethanol fuel. In fact, there are some blended products derived from it such as reformulated gasoline,[1] E10 (fuel composed of 10% of ethanol, 90% of gasoline), and E85 (fuel composed of 85% of ethanol, 15% of gasoline). However, there exists skepticism to consider ethanol as a possible substitute for gasoline due to technical concerns like its low energy content. Figure 2 captures the price differences in terms of dollars per millions of BTU between ethanol fuel and conventional gasoline. Notice that these gaps tend to disappear in those periods related to high crude oil prices.

1 Reformulated gasoline must contain 2.0% of oxygen. Because of the ban on the use of MTBE, ethanol might become the most common source to satisfy the oxygenate requirement imposed on gasoline production. Notice that 10% ethanol blends contain about 3.5% oxygen in the fuel. Therefore, the oxygen content requirement can be accomplished by using a 7.7% blend of ethanol with conventional gasoline.

Figure 2. Prices of Ethanol, Reformulated and Conventional Gasoline



Source: Own elaboration.

In order to obtain reformulated gasoline, conventional gasoline will only be blended with ethanol because of the bans of MTBE. Currently, there are many areas in which this process is observed. Thus, this study focuses on the effects related to an increase in the competition associated with the inclusion of less polluted fuels, such as reformulated gasoline, among existing fuels. This is called the price effect. If this new product very closely competes with existing products of the same manufacturer, then the firm would consider to establish high prices for its other products in the market. However, if the new product closely competes with products of other manufacturers, then a decrease will likely be observed in the prices of other products.

This paper also analyzes the structure of the technology used by refineries and blenders. A multiproduct flexible cost function attempts to give an approach to this technology. In general, this cost function satisfies the rational behavior restrictions imposed by economic theory. Then the estimated marginal costs are incorporated in a monopolistic competition model to calculate the virtual prices of conventional gasoline and other products provided by refineries and blenders in the hypothetical situation in which reformulated gasoline is absent in fuel markets. This study found that conventional gasoline and other product prices are greater than those in the hypothetical case.

I have modified the cost function in a way that it has allowed us to capture some features related to refineries and blenders. For instance, I have considered the multiproduct characteristic of these plants. In addition, I have also allowed the fact that there could be some factors of production that are not variable. In fact, I have included fixed factors such as the fixed asset and energy of this industry.

This paper is organized as follows. The section "Literature review" contains a review of works that study ethanol as a source to generate alternative fuels, and a description of recent regulations imposed on refineries and blenders. This section also includes a brief summary of some applied works related to the estimation of cost functions in other industries. Sections "Consumer's Problem" and "Data" describe the main assumptions needed to specify the monopolistic competition model used to calculate the virtual prices. The section entitled "Estimation on the Leontief Cost Function" establishes the key assumptions to estimate the multiproduct generalized Leontief cost function. "Estimation Results," "Firm's Problem: Pricing Equations," and "Simulation Results" correspond to methods, procedures, data, and conclusions considered in this study.

Literature Review

Ethanol Literature

The production of ethanol could be based on a wide variety of available feedstocks. Indeed, U.S. ethanol fuel is mainly based on corn, but this fuel could be produced from other feedstocks such as crops containing sugar: sugar beets, sugarcane, and sweet sorghum. Moreover, food processing byproducts, such as molasses, cheese whey, beverage waste, and cellulosic materials, including grass and wood, as well as agricultural and forestry residues could be utilized in order to process this biofuel. Almost all the U.S. ethanol production utilize corn for its conversion process and a relatively small amount of ethanol is obtained from sorghum, cheese whey and beverage waste (Shapouri et al., 2006). U.S. ethanol industry has processed 11% of the nation's corn crop and consumed more than 11% of the nation's grain sorghum.[2]

The two main processes used to produce ethanol are dry and wet milling. In the dry-mill process, solids remaining after distillation are dried to produce byproducts and are sold as an animal feed supplement. In the wet-mill process, there are various byproducts such as corn oil, corn gluten feed, corn gluten meal, and carbon dioxide.

The net feedstock costs are defined as the cost of the feedstocks per gallon of ethanol after prices received for byproducts have been subtracted. The net feedstock cost is the most important variable cost which has ranged from 79 cents per gallon of ethanol in 1981 to less than 10 cents per gallon of ethanol in 1987. For the period 1981-1989, net feedstock costs for a wet mill process averaged $0.473 per gallon. For the period 1981-1989, net feedstock costs averaged $0.52 per gallon for a dry mill process (Kane et al., 1989). For the period 2003-2005, net feedstock costs for a wet mill process were calculated at about $0.40 per gallon with ethanol production costs calculated at $1.03 per gallon. For the same period, net feedstock costs for a dry mill process were calculated at about $0.53 per gallon with ethanol production costs calculated at $1.05 per gallon (Shapouri et al., 2006).

Eidman (2006) discusses the features that different renewable liquid fuels such as ethanol-gasoline and biodiesel-petroleum diesel blends have and their impacts on the emission for transportation vehicles. The author also establishes the main sources of demand for the liquid fuels analyzed in his work. He argues that there are four segments that determine the demand for ethanol. Legislation through various federal and state policies represents three of them. The Clean Air Act Amendments of 1990 imposed two major oxygenated requirements: 1) in 1992 it was established that the gasoline sold in carbon monoxide non-attainment areas must contain 2.7% oxygen, and 2) reformulated gasoline (RFG) was required to contain 2% oxygen in the nine worst ozone non-attainment areas. On the other hand, there are two components that constitute the third segment, which are the Federal Excise Tax maintained since 1970 and the fact that some states have mandated that all gasoline sold within the state limits must be blended with a minimum percentage of ethanol. This exemption consists of US$ 0.51 per gallon

2 See Renewable Fuels Association, *Homegrown for the Homeland. Ethanol Industry Outlook 2005*.

of ethanol blended. The fourth segment corresponds to the use of ethanol as an octane enhancing demand to produce premium gasoline. Finally, ethanol can also serve as a fuel extender. This new market for ethanol was motivated by recent increases in petroleum and regular gasoline prices.

Notice that three of the four segments of the demand of ethanol are mandated. This would question the competitiveness of ethanol as a liquid fuel substitute to regular gasoline when the subsidies expire. There are two components that could influence the competitiveness of ethanol: (i) the cost of producing ethanol which relies mainly on corn price; and (ii) the cost of transporting ethanol.

Joseph DiPardo[3] (2005) argues that the production of ethanol from corn is a mature technology that is not likely to see significant reductions in production costs. Alternatively, this author suggests that substantial cost reductions may be possible if cellulose-based feedstocks are used instead of corn. This author also sustains the idea that logistics are also an issue for ethanol use. This idea comes from the fact that in order to supply the west coast market with ethanol production, this has to be sent through the Panama Canal because it is not possible to send ethanol by using pipelines because the moisture in pipelines and storage tanks is absorbed by the ethanol, causing it to separate from gasoline. It should be noted that the Panama Canal has not been a relevant transportation option; for example, in 1998, 38% of ethanol was hauled by truck, 48% was shipped by rail, and 14% was hauled by barge.[4] The ability to produce ethanol from low-cost biomass will be the key to making ethanol competitive with gasoline according to this author.

The main conclusion of DiPardo's study is that with the subsidy due to expire in 2010, it is not clear whether ethanol will continue to receive political support. Thus, the future of ethanol may depend on whether it can compete with crude oil on its own merits. The National Energy Modeling System (NEMS) was used to analyze the potential for cellulose-based ethanol production assuming various technological scenarios and the expiration of subsidies.

Brazil and U.S. ethanol industries[5] amount approximately for more than 30% on the world ethanol production each. I should mention that almost all the Brazilian ethanol production is based on sugarcane while the U. S. ethanol industry

3 See Energy Information Administration for details.

4 See Shapouri et al. (1998) for details.

5 See Renewable Fuels Association (2005).

does not currently utilize this crop for ethanol conversion process. There exist studies about the economic feasibility of U.S. ethanol production based on crops containing sugar, such as sugarcane and sugar beets, but corn appears to be cost competitive with regard to these other feedstocks. Molasses could be considered relatively cost competitive with corn-based ethanol. Therefore, the challenge for the ethanol industry relies on the implementation of biotechnology that could modify grains to become better feedstocks for ethanol.

Literature on the Estimation of Cost Functions

With the objective to calculate the virtual prices, I have planned to establish an econometric model that allows us to estimate the input-output demand functions and the marginal costs.

I will refer to some relevant studies in which demand functions have been estimated for other industries.

This research is mostly based on the analysis and techniques developed by Diewert and Wales (1987) and Friendlaender and Spady (1980). Diewert and Wales (1987) compare two of the traditional flexible functional forms, such as the translog and the generalized Leontief cost functions, with two alternative approaches. They demonstrate that these four functions reached results that are generally comparable in terms of price, output, and technological change effects. Nevertheless, they prove that the symmetric generalized MacFadden and the generalized Barnett cost functions satisfy the curvature restrictions implied by microeconomic theory whereas the former cost functions fail.

Friendlaender and Spady (1980) estimated the demand function for freight transportation by using the single output translog cost function in which freight transportation is considered as a productive input of 96 three-digit manufacturing industries and it was treated like other inputs. They took the first order condition of the cost function and obtained the input demand equations by applying Shephard's lemma. I should mention that they estimated the short-run cost function because they assumed that the analyzed firms are not always in long-run equilibrium.

Another application of single-output cost function estimation is the work done by Rask (1995) in which the author estimated the one-product modified symmetric McFadden cost function for Brazilian sugarcane in order to test for the presence of technological change and economies of scales.

On the other hand, there are many studies in which the single-output assumption has been relaxed. Kumbhakar (1994) estimated the multi-product symmetric generalized McFadden cost function to test the technological progress, overall returns to scale, product specific returns to scale and economies of scope on 12 Finnish foundry plants. Finally, Ivaldi and McCullough (2004) estimated the generalized McFadden cost function as an intermediate step to apply the subadditivity test to the U.S. railroad industry to analyze the feasibility of separating the technology into an infrastructure component and operating component.

In this study I will estimate the input-output demand functions by using the multi- product generalized Leontief cost function. I will basically follow the procedure established by Friendlaender and Spady, but I will utilize the above mentioned flexible functional form by assuming that the analyzed industry produces more than one product. Finally, I will allow the presence of quasi-fixed input in the cost function specification.

I have chosen this functional form because it fits the data well among the other functional forms in terms of the regularity condition and substitution elasticities.[6] These two criteria are particularly important for my study because I am interested that my estimations of demand functions satisfy the microeconomic conditions imposed by the rational behavior of individuals and firms.

Consumer's Problem

The theory on differentiated products has identified two approaches in deriving discrete choice models. In the first approach, called the Non-Address Approach, economy is represented by a single consumer whose preferences exhibit a taste for consuming a variety of products. The second approach, called the Address Approach, assumes that consumers have different tastes for different brands. In the last approach, consumers buy at most one unit of the brand. The difference between these two approaches relies on their assumptions.

In the first approach, the product variety is originated from the taste of variety rather than the variety of consumer preferences related to the second approach. I have decided to implement the first approach in this study because the micro

6 See Fisher, Fleissig and Serletis (2001) and Diewert and Wales (1987).

level data of households is easily incorporated. I should emphasize that this is a general equilibrium model. In other words, consumer's demand is generated from a utility maximization problem and firms, which are assumed to be modelled as price-setting oligopolists, maximize their profits.

The U.S. liquid fuel market will be characterized by using a structural model which attempts to capture some of the main features of this market. A large market share of the total motor-fuel use in the U.S. fuel industry is destined to private and commercial use evidencing that consumers play an important role in the analysis of this sector. Gasoline is the dominant product in the U.S. fuel market. In fact, gasoline and gasohol consumption in private and commercial use accounted for 74.3% of the total fuel consumption according to Highway Statistics (2005).

I will then assume that there is a representative consumer whose preferences are represented by a constant elasticity of substitution (CES) utility function, used by Dixit and Stiglitz (1977):

$$u = U\left(y_0, \left\{\sum_k y_k^{\rho}\right\}^{1/\rho}\right) \qquad \textit{Equation 1}$$

Where $0 < \rho < 1$ in order to guarantee concavity and zero values of y_k which represents the consumed amount of different fuels. The budget constraint is written as follows:

$$y_0 + \sum_{i=1}^{n} p_k y_k = I \qquad \textit{Equation 2}$$

Where p_k is the price of the different kind of fuels produced by refineries and blenders. Notice that y_0 is a numeraire good which implies that the income is in terms of this numeraire.

Given the product prices $\{p_1^*, ..., p_k^*, ..., p_K^*\}$, the list of quantities $\{y_1^*, ..., y_k^*, ..., y_K^*\}$ is an equilibrium if y_k solves the following problem:

$$\max_{\{y_1,\ldots,y_K\}} U\left(y_0, \left\{\sum_k y_k^{\rho}\right\}^{1/\rho}\right) \qquad \textit{Equation 3}$$

subject to:

$$i)\ y_0 + \sum_{k=1}^{n} p_k^* y_k = I \qquad \textit{Equation 4}$$

$$\text{ii) } non - negativy \qquad \textit{Equation 5}$$

Solving the consumer's problem, I obtain the following demand equations:[7]

$$y_l^* = \frac{\left\{\sum_k y_k^{*\rho}\right\}^{1/\rho}}{\sum_{k=1}^{n} p_k^{*-\rho/1-\rho}} p_l^{*1/\rho}; \forall k, l = 1, \dots, K \qquad \textit{Equation 6}$$

This CES utility function has similar properties to those of the "discrete choice" model, such as logit and nested logit models, but differs from the discrete choice model by assuming continuity of the quantities demanded of the discrete good.[8] For instance, the discrete choice utility functions suffer from the problem of the "independent of irrelevant alternatives" (IIA). In fact, the problem with the logit model is that the calculated demand elasticities are independent from the prices or characteristics of any third product, i.e. the independent of irrelevant alternatives property, which will imply that the cross price elasticities of all goods with regard to a third good are equal. The proposed CES function has the same characteristic with respect to the calculated cross price elasticities.[9] Finally, Anderson et al. (1989) showed that the logit and the CES models can be reconciled by imposing some conditions in the characteristics space.[10]

7 See Dixit and Stiglitz (1977) for details.

8 Feenstra (2004) has proven that the discrete choice function tends to a CES function by sharing the same assumptions.

9 Notice that the own price elasticity is given by $\epsilon_{kk} = \frac{-1}{(1-\rho)}$. On the other hand, cross price elasticities are given by $\epsilon_{kl} = \left(\frac{1}{1-\rho}\right) \frac{p_l^{\frac{-1}{1-\rho}}}{\sum_l^K p_l^{-\rho/1-\rho}}$, where we can observe that these elasticities are symmetric.

10 For details, see Anderson, de Palma and Thisse (1989).

Estimation of the Leontief Cost Function

The vector of inputs, denoted as $x^* \equiv \{x_1^*, x_2^*, ..., x_N^*\}$, , minimizes the refinery and blender's problem defined as:

$$C^*(w, y, t) \equiv \min_{\{x_1^*, x_2^*, ..., x_N^*\}} \left\{ \sum_{i=1}^{N} w_i x_i \, : \, f^*(x; t) \geq y, x \geq 0_N \right\} \qquad \textit{Equation 7}$$

Where the minimization problem is subject to: i) the non-negativity constraint, and ii) the technology of a refinery and blender that could be represented by a production function, denoted as $f_k^*(x; t)$, such that $y_k^* = f_k^*\{x_1^k, x_2^k, ..., x_N^k; t\} \; \forall K = 1, 2, ... K$, and y_k^* is the maximal amount of the k-th output that can be produced by using this input vector in period t. It is worth noting that I will assume a multiproduct technology, that is, the refineries and blenders are allowed to produce more than one output by using the same vector of inputs. Thus, the technology constraint is written, in vector terms, as $f^*(x; t) \geq y$.

According to microeconomic restrictions imposed by rational economic behavior, the cost function $C^*(*)$ will satisfy two conditions: i) it will be linearly homogenous in the input prices, and ii) it will be concave in the input prices. I also assume that $C^*(*)$ is a twice continuous differentiable function with respect to all its arguments, such as prices, output, and technological progress variable represented as t.

I will consider a specific functional form that will approximate the cost function, $C^*(*)$, in order to estimate the input-output demand functions. I will analyze their properties in terms of the regularity conditions and the precision of the estimations with respect to input-output price elasticities. The functional form that I will apply, as was mentioned in the previous section, is the multiproduct symmetric generalized Leontief cost function.

Before I proceed with the analysis of the flexible cost functions, I will define the cost model as follows:

$$C = C\{w_o, w_e, w_M, w_{ng}, w_l, y_{rf}, y_{cv}, y_{oth}; \bar{A}, \bar{E}, \alpha, \beta, \gamma\pi, \emptyset, t\} \qquad \textit{Equation 8}$$

Where:

$C \equiv$ the conditional cost function with a fixed factor

$w_o \equiv$ oil prices

$w_e \equiv$ ethanol prices

$w_M \equiv$ MTBE prices

$w_{ng} \equiv$ natural gas prices

$w_l \equiv$ wage index

$y_{rf} \equiv$ amount produced of reformulated gasoline

$y_{cv} \equiv$ amount produced of conventional gasoline

$y_{oth} \equiv$ amount produced of other products

$t \equiv$ proxy variable for the state of technical knowledge at time t

$\overline{A} \equiv$ amount of fixed assets used by refineries and blenders

$\overline{E} \equiv$ amount of energy used by refineries and blenders

$\alpha, \beta, \gamma, \pi, \emptyset \equiv$ parameters assumed to be exogenously given

Multiproduct Symmetric Generalized Leontief cost function (MGL)

Consider the following functional form:

$C(w, y, \bar{A}, \bar{E}, t)$ *Equation 9*

$$= \sum_{i=1}^{N}\sum_{j=1}^{N} b_{ij} w_i^{1/2} w_j^{1/2} \left(\sum_{k=1}^{K} \delta_k y_k\right) + \sum_{i=1}^{N} b_i w_i$$

$$+ \sum_{i=1}^{N}\sum_{k=1}^{K} b_{ik} w_i t y_k + b_t \left(\sum_{i=1}^{N} \propto_i w_i\right) t$$

$$+ \sum_{l=1}^{L}\sum_{k=1}^{K} b_{lk} \left(\sum_{i=1}^{N} \beta_i w_i\right) y_l y_k + b_{tt} t^2 \left(\sum_{i=1}^{N} \gamma_i w_i\right)\left(\sum_{k=1}^{K} \delta_k y_k\right)$$

$$+ b_{aa} \left(\sum_{i=1}^{N} \pi_i w_i\right) \bar{A} \left(\sum_{k=1}^{K} \delta_k y_k\right) + b_{ee} \left(\sum_{i=1}^{N} \emptyset_i w_i\right) \bar{E} \left(\sum_{k=1}^{K} \delta_k y_k\right); i, j$$

$$= 1,2, \dots, N; k = 1,2, \dots, K$$

With $b_{ij} = b_{ij} \forall$i, j = 1, 2, ..., N. The cost function defined in (9) is linearly homogenous in input prices $\underline{W \geq 0}$ and it has $\frac{(N + K)(N + K + 1)}{2}$ parameters which is just the right number for equation (9) to be a flexible functional form. The 3N number, α_i, β_i, and γ_i, are assumed to be exogenously given. In particular, I will set all of these parameters to be equal to the average amount of input used over the sample period. Notice that the letters *i*, *j* stand for the amount of inputs and for the amount of outputs.

I will treat ethanol as another input used by refineries to produce different products. The refineries utilized the following inputs: crude oil, natural gas and some oxygenates, such as ethanol and MTBE, to produce aggregate outputs such as reformulated gasoline (y_{rf}), conventional gasoline (y_{cf}), and others (y_{oth}). I have also included the fixed asset and energy inputs, ($\bar{A}$) and ($\bar{E}$), in our cost function specification. These variables represent our quasi-fixed inputs which were defined in this manner due to data limitation.

I assume that the input prices, $w_i \forall_i = o, e, M, ng, l$, and the outputs, y_{rf}, y_{cv} and y_{oth}, are exogenous. But I assume that the input quantities, $x_i, \forall_i = o, e, M, ng, l$, and the total cost, C, are endogenous.

In order to get a mathematical expression for the input demand functions, I apply the Shephard's lemma which states that the cost-minimizing demand for input i can simply be derived by differentiating the cost function with respect to w_i. Therefore, the optimal factor demands are obtained by differentiating equation (9) with respect to w_i, yielding:

$$\frac{\partial C(*, y; \bar{A}, \bar{E}, t}{\partial w_i} = x_i \qquad \textit{Equation 10}$$

$$= \frac{1}{2}\sum_{j=1}^{N} b_{ij}\left(\frac{w_j}{w_i}\right)^{1/2}\left(\sum_{k=1}^{K}\delta_k y_k\right) + b_i + \sum_{k=1}^{K} b_{ik} y_k t + b_t \alpha_i t$$

$$+ \sum_{l=1}^{L}\sum_{k=1}^{K} b_{lk}\beta_i y_l y_k + b_{tt} t^2 \gamma_i \left(\sum_{k=1}^{K}\delta_k y_k\right) + b_{aa}\pi_i \bar{A}\left(\sum_{k=1}^{K}\delta_k y_k\right)$$

$$+ b_{ee}\emptyset_i \bar{E}\left(\sum_{k=1}^{K}\delta_k y_k\right); \; \forall\, i,j = o,e,M,ng,l; k = rf,cv,oth$$

I then divide the equation (10) by the amount of the refinery and blender's total production, so the input-output demand functions are as follows:

$$\frac{\frac{\partial C(*, y; \bar{A}, \bar{E}, t)}{\partial w_i}}{y} = \frac{x_i}{y} \qquad \textit{Equation 11}$$

$$= \frac{1}{2}\sum_{j=1}^{N} b_{ij}\left(\frac{w_j}{w_i}\right)^{1/2} + b_i y^{-1}$$

$$+ \sum_{k=1}^{K} b_{ik} y_k t y^{-1} + b_t \alpha_i t y^{-1}$$

$$+ \sum_{l=1}^{L}\sum_{k=1}^{K} b_{lk}\beta_i y_l y_k y^{-1} + b_{tt} t^2 \gamma_i + b_{aa}\pi_i \bar{A} + b_{ee}\emptyset_i \bar{E}; \; \forall\, i,j$$

$$= o,e,M,ng,l; k = rf,cv,oth$$

Where $y = (\sum_{k=1}^{K} \delta_k y_k) \forall k = rf, cv, oth$. As I mention there are six inputs: oil, ethanol, MTBE, energy, fixed assets, and labor. The three outputs, y_{rf}, y_{cv} and y_{oth} , are captured by the production of reformulated gasoline, conventional gasoline and other products. The multi-product generalized Leontief cost-minimizing input-output equations are derived in the appendix.

I should remark that one disadvantage of using the MGL cost function is that global concavity will be satisfied if I impose the restriction of non-negativity on all the coefficients b_{ij} for $i \neq j$, but this would rule out complementarity between all pair of inputs.

Data

This analysis utilized the following variables: i) oil production, ii) ethanol production, iii) MTBE production, iv) reformulated gasoline production, v) conventional gasoline production, vi) natural gas production, vii) fixed assets for petroleum and coal products, viii) energy used by refineries and blenders, ix) number of worker in the industry, x) oil price, xi) ethanol price, xii) M price, xiii) natural gas price, and xiv) wage index. I should mention that most of these variables were obtained through the Energy Information Administration (EIA) database which is available on its website.[11] It is worth noting that all of these variables were selected from the refinery and blender viewpoint. The production of ethanol, oil, MTBE and natural gas represent the amount of these inputs used for refineries and blenders in the U.S. in order to produce reformulated and conventional gasoline, and other products as outputs.

All of these input and output productions are in terms of thousand barrels while all of the price variables are in terms of dollars per barrels. The fixed assets variable was obtained from the database of the Bureau of Economic Analysis.[12] Finally, the number of worker and the wage index were collected from the database of the Bureau of Labor Statistics.[13] Table 1 contains the basic descriptive statistics of the database employed in this study.

11 The website of the Energy Information Administration is: www.eia.doe.gov.

12 The website of the Bureau of Economic Analysis is: www.bea.gov.

13 The website of the Bureau of Labor Statistics is: www.bls.gov.

Table 1. Descriptive Statistics for the Period 09/94-12/05

Input-Output	Variable	Units	Mean value	St. Deviation
Oil	Production	Millions of barrels	452.012	25.396
	Price	Dollars per barrel	27.542	11.998
Ethanol	Production	Millions of barrels	2.411	2.184
	Price	Dollars per barrel	1.272	0.249
MTBE	Production	Millions of barrels	6.465	1.619
	Price	Dollars per barrel	0.917	0.240
Natural Gas	Production	Millions of barrels	12.887	2.2
	Price	Dollars per thousand cubic feet	3.464	1.917
Labor	Number of Worker	Thousands	130.151	10.327
	Wage index		142.992	14.196
Fixed Assets		Billions of dollars	61.4	4.694
Energy		Dollars per barrel	1.27	0.37
CV Gas	Production	Millions of barrels	165.950	9.994
	Price	Cents per gallon	142.949	36.617
RF Gas	Production	Millions of barrels	75.626	12.722
	Price	Cents per gallon	153.049	38.179
Others	Production	Millions of barrels	277.468	18.022
	Price	Cents per gallon	91.424	38.718

Source: Own elaboration.

Estimation Results

The empirical section is focused on the estimation of the system of demand functions derived from the MGL cost function. As such, I have allowed for no constant returns to scale technology and no technological change assumptions in our specification. In what follows, I describe what our main tasks for this present study were.

I have tested for potential endogeneity problems whose results have certainly determined the best econometric procedure to estimate those systems of equations explained in previous sections. I did not find any evidence for the presence of endogeneity in the MGL framework according to the Hausman test. Thus, the input-output demand functions were estimated by using the nonlinear iterative Zellner's seemingly unrelated regression (NLITSUR) procedure whose results are reported in the table A.1. I have used NLITSUR because one would expect disturbances across input-output equations to be contemporaneously correlated, implying that the disturbance covariance matrix would be non-diagonal.

Economies of Scale and Economies of Scope

Table 2 contains the estimation of key parameters, such as the own and cross price elasticities of input-output demands, the economies of scale and scope for refineries and blenders.

Table 2. Economies of Scale and Scope

Equation	Input-Output	Variable	Mean value	St. Dev/St. Errors
Demand	Oil	Own price elasticity	-0.00933	0.00277
	Ethanol		-145.706	0.4334
	MTBE		-0.52942	0.1575
	Ng		-0.38715	0.1152
	Labor		-0.44416	0.1321
		Overall Returns to scale	2.27	0.0578
		PSRTS Conventional gas	2.66	0.3151
		PSRTS Reformulated gas	2.84	0.1009
		PSRTS Other products	2.02	0.0956
		Economies of Scope	0.928	0.0419

Source: Own elaboration.

As it can be observed in Table 2, all own price elasticities indicate that these inputs are price inelastic, in the sense that a small percentage variation in the price will negligibly change the amount of input-output demand, except for ethanol whose own price elasticity is greater than −1. In other words, ethanol is sensitive to price variations compared to the rest of inputs. Notice that in Table 3 cross price elasticities are suggesting that crude oil is a substitute input with regard to ethanol, MTBE, and natural gas in the production process. According to our calculations, crude oil and labor seem to be complement, but I cannot fully rely on this result because this cross price elasticity is not significant at any level.[14] Thus, cross price elasticities imply that the different types of materials are substitutes for crude oil.

Table 3. Own and Cross Price Elasticities (standard errors are reported in parenthesis)

Input-Output	Oil	Ethanol	MTBE	Ng	Labor
Oil	-0.00933	0.001984	0.00527	0.002113	-0.00005
	(0.00277)	(0.00107)	(0.00167)	(0.00162)	(0.000095)
Ethanol	0.222531	-1.45706	-0.20098	0.081136	0.000425
	(0.1200)	(0.4334)	(0.0877)	(0.0760)	(0.00896)
MTBE	0.253337	-0.08598	-0.52942	-0.15701	0.003531
	(0.0799)	(0.0375)	(0.1575)	(0.0455)	(0.00309)
Ng	0.104258	0.035687	-0.16142	-0.38715	-0.00365
	(0.0800)	(0.0334)	(0.0467)	(0.1152)	(0.00280)
Labor	0.03167	0.002502	0.048621	-0.04892	-0.44416

Source: Own elaboration.

On the other hand, in Table 2, I have also reported the mean values of the economies of scale and scope. In order to obtain those measurements of cost advantages, I have followed the approach done by Bailey and Friendlaender (1982). These authors extended the traditional concepts of economies of scale and scope by incorporating the multiproduct nature of the firms.

Economies of scale exists if the total cost increases less proportionally than output. I utilized the following expression:

$$S \equiv AC/MC = \frac{C(Y)}{Y\frac{\partial C}{\partial Y}} \qquad \textit{Equation 12}$$

Where *AC* and *MC* denote the average and marginal costs, respectively. For simplicity, I have omitted other arguments in the cost function except for the vector

14 See Table A.1 for additional details.

of products represented by Y. Alternatively, the above expression is the reciprocal of the elasticity of cost with regard to output.

If $\gtreqless 1$, then the firm exhibits increasing, constant, or decreasing returns to scale. I have found evidence of economies of scale since $S = 2.27$ in average. I have also calculated the product-specific returns to scales ($PSRTS_K$) which have shown evidence of economies of scale in all three products.[15]

The existence of positive economies of scope imply that a single firm can jointly produce a given level of output of each product more cheaply than the total cost of separate production at the given level of output. The economies of scope for our specific case are given by:

$$ESC = \frac{C(y_1, 0{,}0) + C(0, y_2, 0) + C(0{,}0, y_3)}{C(y_1, y_2, y_3)} \qquad \textit{Equation 13}$$

If $\gtreqless 0$, then economies of scope exist or not. The estimates of ESC are positive for all the years. The mean value of these estimates are reported in Table 1. The presence of economies of scope is relevant in this industry since some of its inputs are indivisible (e.g. some machineries) and they can be assigned to the production process of more than one product.

The evidence of the presence of economies of scale and economies of scope has a direct implication on the conjecture of natural monopoly in this industry. It is well known that if an industry exhibits both product-specific economies of scale and economies of scope at that level, then subadditivity will likely exist. Subadditivity of the cost function simply implies that the production of all possible combinations of commodities could be accomplished at least cost by a single multi-product firm in this case. Therefore, the analyzed industry satisfies the definition of natural monopoly that requires the subadditivity of the cost function to be proven.

15 The product-specific return to scale is given by $PSRTS_K = \frac{C(Y) - C(y_1, y_2, \ldots, y_{k-1}, 0, y_{k+1}, \ldots, y_L}{MC_k}$

Marginal Cost Estimations

The marginal costs[16] for the three products are reported below. The average marginal cost for conventional gasoline is about $31.707 per barrel or equivalently $0.755 per gallon, while reformulated gasoline is associated to an average marginal cost of $32.142 per barrel ($0.765 per gallon). Notice that the dispersion of the regular gasoline marginal cost is greater than that of reformulated gasoline.

Table 4. Marginal Costs

Equation	Input-Output	Variable	Mean value	St. Dev/St. Errors
Cost	Conventional Gas	Marginal Cost ($/barrel)	31.707	12.009
	Reformulated Gas		32.142	11.554
	Other		49.514	17.066

Source: Own elaboration.

"The evidence of the presence of economies of scale and economies of scope has a direct implication on the conjecture of natural monopoly in this industry. It is well known that if an industry exhibits both product-specific economies of scale and economies of scope at that level, then subadditivity will likely exist".

The difference of the estimated marginal costs between conventional and reformulated gasoline captures the fact that refiners had to include the costs of meeting the standards of CAAA1990 which mandated the production of reformulated gasoline since 1995 with the inclusion of some stringent requirements afterwards. Estimated marginal costs are presented in the appendix for the 1994-2005 period.

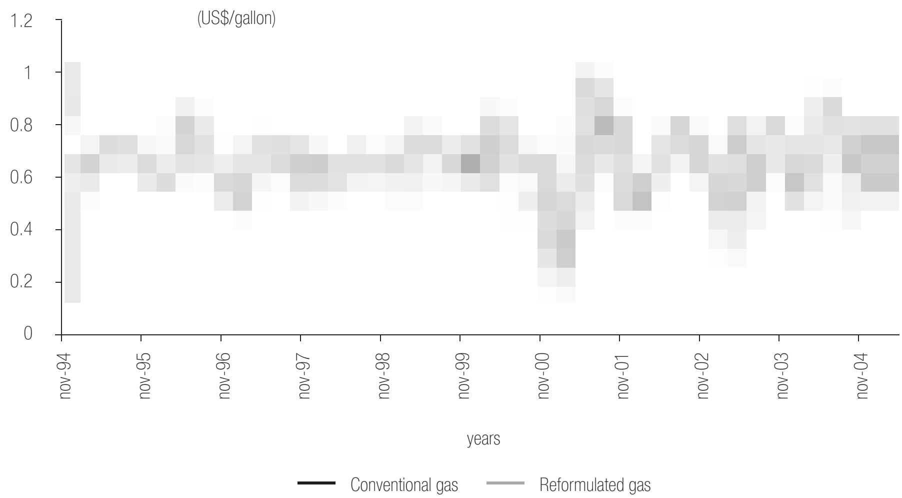
Prices paid by consumers at any gas station reflect the cost of crude oil to refiners, refinery processing, marketing and distribution costs, and retail station costs.[17] Average petroleum price in 2004 was $36.98 per barrel and represented 47% of the total cost of a gallon of conventional gasoline. Moreover,

16 I have calculated the marginal costs of each products by multiplying the input price vector time the vector of second derivative of the cost function with respect to the products.

17 See Energy Information Administration Brochures: *A Primer on Gasoline Prices*.

refining costs comprise about another 19% of the retail price of gasoline. Having just taken into account the cost of crude oil and refinery processing, the margin of conventional gasoline is, on average, \$0.64 per gallon in 2004, while the estimated margin averages \$0.60 per gallon in the same year. There was a difference of four cents per gallon between the observed and the estimated margin in 2004. In general, I believe that the estimated price-cost margins are coherent with the observed data since the cost functional form appropriately reflects the technology of refineries and blenders. Figure 3 reports the price-cost margins for conventional and reformulated gasoline.

Figure 3. Estimated Price-Cost Margins



Source: Own elaboration.

Lerner Indices

The well-known measurement of the amount of monopoly power called the Lerner index is obtained by dividing the price-cost margins by price. This definition of monopoly power is based on the firm's ability to set price above marginal cost. The Lerner index is defined as:

$$\frac{p^m - C'}{p^m} = \frac{1}{\in} \qquad \textit{Equation 14}$$

Where $\in = \frac{-D' p^m}{D}$ and $D(p^m)$ denotes the demand elasticity at the monopoly price, p^m, and monopoly output, respectively. The left-hand side of the equation (14) represents the Lerner index. It is worth mentioning that I have incorporated the estimated short-run marginal cost into the above equation in order to estimate this index. The Lerner index is inversely proportional to demand elasticity. Therefore, if the index tends to zero, demand elasticity will approach to infinity. The Lerner indices for reformulated and conventional gasoline on average for the period under analysis are reported in Table 5.

Table 5. Lerner Indices

Year	Conventional Gas	Reformulated Gas
1995	0.57	0.57
	(0.04)	(0.03)
1996	0.51	0.53
	(0.05)	(0.06)
1997	0.50	0.52
	(0.06)	(0.06)
1998	0.57	0.59
	(0.04)	(0.04)
1999	0.53	0.57
	(0.05)	(0.05)
2000	0.39	0.43
	(0.14)	(0.06)
2001	0.39	0.44
	(0.14)	(0.13)
2002	0.47	0.49
	(0.03)	(0.03)
2003	0.36	0.40
	(0.08)	(0.07)
2004	0.33	0.38
	(0.04)	(0.04)
2005	0.28	0.29
	(0.25)	(0.28)

Source: Own elaboration.

As observed in Table 5, the Lerner index for reformulated gasoline is higher than that related to conventional gasoline in all the years. As it was previously mentioned, greater indices imply lower values of demand elasticities. Therefore, given that the multi-product natural monopoly hypothesis has not been excluded for this industry, I examined what type of pricing rule is being implemented by refiners and blenders. I found that this industry is a discriminating natural monopoly in its pricing scheme in 87.2% of the total observations. A discriminating monopoly that sells a strictly positive amount in each market charges more in markets with lower elasticity of demand. Finally, I verify that this price scheme is also suggesting a subsidy-free pricing rule since the observations do not support the cross-subsidization pricing evidence[18] which could have been very attempting to establish.

Firm's Problem: Pricing Equations

This section will be based on the studies done by Hausman (1997) and Hausman and Leonard (2002). Both studies provide the conceptual framework to analyze the introduction of new products. In general, the introduction of a new product is expected to benefit consumers because it will increase the variety in a market. This is called the variety effect.

On the other hand, the introduction of a new product increases the competition among the existing products. This is called the price effect. If this new product very closely competes with existing products of the same manufacturer, then the firm would consider to establish high prices for its other products in the market. However, if the new product closely competes with the products of other manufacturers, then a decrease will likely be observed in the prices of the other products.

"The introduction of a new product increases the competition among the existing products. This is called the price effect".

18 Cross-subsidization is said to exist when the price of one product is set so as to generate additional revenues that are used to subsidize the production of another good supplied by a firm. No observation satisfies the conditions under which the price of the low-cost product is too high and the price of the high-cost product is too low.

The results of these models depend strongly on the assumption related to the market structure. I would assume any kind of market structure such as Bertrand, Cournot, and even collusion.

The competitive effects associated to the introduction of a new product would be quantified by implementing either a direct or an indirect approach. By using the direct approach I need information pre and post the introduction of reformulated gasoline. In this study I rule out the direct approach due to data limitations. The indirect approach allows us to calculate the price effect by using the current information, i.e., the post introduction information.

In what follows, I will define the firm's problem and obtain the first order necessary conditions in order to specify the price-margin equations for a multiproduct monopolistic competition scheme.

The list of prices and quantities $\{p_1^*, p_2^*, ..., p_K^*; y_1^*, y_2^*, ..., y_K^*\}$ is a Bertrand-Nash equilibrium if:

i) Given $p_1^*, ..., p_{K-1}^*, p_{K+1}^*; p_K$ solves the following problem:

$$\max_{\{p_1,\dots,p_k,\dots,p_K\}} \sum_{k=1}^{K} p_k D_k(p) - C\big(D_1(p), \dots, D_K(p)\big); \forall\, k = 1,2, \dots, K \qquad \textit{Equation 15}$$

ii) $y_k^* = D(p^*); p_1^*, p_2^*, ..., p_K^*; y_1^*, y_2^*, ..., y_K^* \geq 0$

Observe from equation (15) that I have assumed a multiproduct monopolistic competition. Notice that I have kept the assumption of multiproduct nature of the firms introduced in section 4 with the estimation of the cost function. On the other hand, I have assumed a Bertrand market structure where firms set prices rather than quantities. The Bertrand structure is more convenient given the fact that firms are able to modify prices faster and at less cost than to change quantities due to technological and capacity constraints related to them. The first order necessary conditions of the above problem are as follows:[19]

19 See Tirole (1988) for details.

$$D_k(p) + \sum_{l=1}^{K} (p_l - mc_l) \frac{\partial D_l(p)}{\partial p_k} = 0; \ \forall \ l, k = 1, \dots, K \qquad \textit{Equation 16}$$

Finally, multiplying the equation (16) by $\frac{p_k}{\sum_{l=1}^{K} p_l D_l}$, I have:

$$s_k + \sum_{l=1}^{K} \left(\frac{p_l - mc_l}{p_l} s_l \right) \in_{lk} = 0; \ \forall \ l, k = 1, \dots, K \qquad \textit{Equation 17}$$

Where the first term, s_k , represents the share of the *kth* fuel and the second term of the equation (17) could be thought of as the price-cost markups multiplied by cross price elasticities of different fuels. I have solved the mentioned system of equations by calculating the price-cost markups. In order to solve that system, I have incorporated my estimations of the marginal costs that were done in the previous section.

Simulation Results

In this section, I try to calculate the indirect price effects of the reformulated gasoline introduction. The reservation prices are defined as the prices for which a refiner or blender is at break-even point and, therefore, indifferent between producing and not producing reformulated gasoline. The reservation o virtual price for reformulated gasoline, with this utility function specification, is infinite. But I still can approximate the price effects related to the introduction of a new good in the fuel market.

I have incorporated the estimation of the marginal costs into the price-cost margin equations in order to recover not only the Lerner indexes, but also the price changes. I have solved the system of equations (17) and introduced the assumption that the demand for reformulated gasoline is set to zero by using the Newton method, the results are reported in Tables 6 to 9. In those tables, I have reported the values of the Lerner indexes and the prices under both scenarios, i.e. with the presence of reformulated gasoline and simulating the absence of this fuel. Table 10 contains the percentage differences in both the Lerner Indexes and prices. These percentage differences reflect the variation between the current situation, with reformulated gasoline in the fuel market, and the hypothetical scenario in terms of the Lerner indexes and prices.

Table 6. Lerner Indexes (with reformulated gasoline in the market)

ρ	Conventional Gasoline	Other Products
0.1	0.902 (0.000256813)	0.916 (0.0066126)
0.2	0.8017 (0.000221175)	0.815 (0.0063278)
0.3	0.702 (0.000185759)	0.714 (0.0060585)
0.4	0.601 (0.000151074)	0.613 (0.0058068)
0.5	0.501 (0.000118426)	0.512 (0.0055692)
0.6	0.401 (0.000090942)	0.412 (0.0053191)
0.7	0.300 (0.000072930)	0.310 (0.0049415)
0.8	0.200 (0.000055790)	0.209 (0.0040459)
0.9	0.100 (0.000015653)	0.105 (0.0021187)

Source: Own elaboration.

Table 7. Lerner Indexes (simulating the absence of reformulated gasoline in the market)

ρ	Conventional Gasoline	Other Products
0.1	0.901 (0.000107118)	0.911 (0.0046727)
0.2	0.801 (0.000094421)	0.810 (0.0044659)
0.3	0.701 (0.000081998)	0.710 (0.0042700)
0.4	0.601 (0.000070058)	0.609 (0.0040865)
0.5	0.500 (0.000058980)	0.508 (0.0039132)
0.6	0.4002966 (0.000049319)	0.4076936 (0.0037323)
0.7	0.300 (0.000041023)	0.307 (0.0034654)
0.8	0.200 (0.000029624)	0.206 (0.0028430)
0.9	0.100 ($8.0006789x10^{6}$)	0.104 (0.0014997)

Source: Own elaboration.

Table 8. Prices ($/gallons) (with reformulated gasoline in the market)

ρ	Conventional Gasoline	Other Products
0.1	7.746	13.885
0.2	3.830	6.345
0.3	2.544	4.116
0.4	1.905	3.046
0.5	1.522	2.418
0.6	1.267	2.004
0.7	1.086	1.712
0.8	0.950	1.493
0.9	0.844	1.321

Source: Own elaboration.

Table 9. Virtual Prices ($/gallons) (simulating the absence of reformulated gasoline in the market)

ρ	Conventional Gasoline	Other Products
0.1	7.66	13.118
0.2	3.812	6.195
0.3	2.537	40.568
0.4	1.902	30.160
0.5	1.521	2.400
0.6	1.267	1.994
0.7	1.085	1.704
0.8	0.950	1.488
0.9	0.844	1.319

Source: Own elaboration.

Table 10. Lerner Indexes and Price Differences (in percentage changes)

ρ	Lerner Indexes Conventional Gasoline	Other Products	Prices Conventional Gasoline	Other Products
0.1	0.123	0.581	1.079	5.527
0.2	0.120	0.611	0.467	2.363
0.3	0.117	0.651	0.265	1.428
0.4	0.111	0.705	0.163	0.980
0.5	0.104	0.782	0.102	0.718
0.6	0.092	0.898	0.061	0.546
0.7	0.073	1.076	0.032	0.420
0.8	0.041	1.338	0.011	0.306
0.9	0.006	1.571	0.001	0.163

Source: Own elaboration.

I have calculated the percentage changes for the different values of $\rho \in (0,1)$. All the changes are positive; this implies that the Lerner indexes and prices in the current situation are higher than those in the hypothetical scenario. Moreover, notice that as $\rho \mapsto 1$, these differences tend to decrease, except for the Lerner index related to the other products. Recall, that when $\rho \mapsto 1$, all products are perfect substitutes and therefore diversity is not valued at all. Hence, as long as is close to one, price differences become negligible for both conventional gasoline and the other products produced by refineries and blenders.

Conclusions

The main goal of this study has been to estimate the virtual prices for conventional gasoline and other products provided by refineries and blenders in the hypothetical situation in which reformulated gasoline is absent in fuel markets. As an intermediate step, I estimated the marginal costs for the three products selected in this research by using a Leontief multiproduct cost function. In general, this cost function satisfies the rational behavior restrictions imposed by economic theory. The estimated marginal costs were then incorporated in the price-margin system of equations. Solving this system of equations, I have found that conventional gasoline and other product prices are greater than those in the mentioned hypothetical case. This result reflects the fact that consumers are being charged with high prices in order to have available a fuel associated with improved quality properties established by the Environmental Protection Agency (EPA). On the other hand, I should emphasize that when $\rho = 1$, all the products are perfect substitutes, i.e. consumers are not interested in product diversity and thus in this case they do not care about the quality of fuels. The calculated price differences, reported in Table 10, confirm this intuition. I have noticed that as long as $\rho \mapsto 1$ these price changes become positively negligible. Hence, if the parameter associated to the utility function of consumers tends to one, then consumers are less willing to pay high prices for those clean fuels.

Another contribution of this paper has been the estimation of the demand equation for ethanol as input in the production processes refineries and blenders. The demand for ethanol can be forecasted by using the estimated parameters of demand systems. Projections for the ethanol demand might be analyzed taking into account federal and state tax schedules and some policy implications might be established. Finally, this study could be extended to calculate the consumer's welfare effect under the same hypothetical scenario.

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Appendix

Appendix 1. Input-output demand equations derived from the Leontief cost function

Equation 18

$$d_o = \frac{1}{2}\left[b_{oo} + b_{oe}\left(\frac{w_e}{w_o}\right)^{\frac{1}{2}} + b_{oM}\left(\frac{w_M}{w_o}\right)^{\frac{1}{2}} + b_{ong}\left(\frac{w_{ng}}{w_o}\right)^{\frac{1}{2}} + b_{lo}\left(\frac{w_l}{w_o}\right)^{\frac{1}{2}}\right] + b_o y^{-1}$$
$$+ \left[b_{or}\frac{ty_{rf}}{y} + b_{oc}\frac{ty_{cv}}{y} + b_{ooth}\frac{ty_{oth}}{y}\right] + b_t \alpha_o t y^{-1}$$
$$+ \beta_o \left[b_{rr}\frac{y_{rf}^2}{y} + b_{cc}\frac{y_{cv}^2}{y} + b_{othoth}\frac{y_{oth}^2}{y} + 2b_{rc}\frac{y_{cv}y_{rf}}{y} + 2b_{roth}\frac{y_{rf}y_{oth}}{y}\right.$$
$$\left. + 2b_{coth}\frac{y_{cv}y_{oth}}{y}\right] + b_{tt}\gamma_o t^2 + b_{aa}\pi_o \bar{A} + b_{engeng}\emptyset_o \bar{E}$$

Equation 19

$$d_e = \frac{1}{2}\left[b_{ee} + b_{oe}\left(\frac{w_o}{w_e}\right)^{\frac{1}{2}} + b_{Me}\left(\frac{w_M}{w_e}\right)^{\frac{1}{2}} + b_{nge}\left(\frac{w_{ng}}{w_e}\right)^{\frac{1}{2}} + b_{le}\left(\frac{w_l}{w_e}\right)^{\frac{1}{2}}\right] + b_e y^{-1}$$
$$+ \left[b_{er}\frac{ty_{rf}}{y} + b_{ec}\frac{ty_{cv}}{y} + b_{eoth}\frac{ty_{eth}}{y}\right] + b_t \alpha_e t y^{-1}$$
$$+ \beta_e \left[b_{rr}\frac{y_{rf}^2}{y} + b_{cc}\frac{y_{cv}^2}{y} + b_{othoth}\frac{y_{oth}^2}{y} + 2b_{rc}\frac{y_{cv}y_{rf}}{y} + 2b_{roth}\frac{y_{rf}y_{oth}}{y}\right.$$
$$\left. + 2b_{coth}\frac{y_{cv}y_{oth}}{y}\right] + b_{tt}\gamma_e t^2 + b_{aa}\pi_e \bar{A} + b_{engeng}\emptyset_e \bar{E}$$

Equation 20

$$d_M = \frac{1}{2}\left[b_{MM} + b_{oM}\left(\frac{w_o}{w_M}\right)^{\frac{1}{2}} + b_{Me}\left(\frac{w_e}{w_M}\right)^{\frac{1}{2}} + b_{ngM}\left(\frac{w_{ng}}{w_M}\right)^{\frac{1}{2}} + b_{lM}\left(\frac{w_l}{w_M}\right)^{\frac{1}{2}}\right] + b_M y^{-1}$$

$$+ \left[b_{Mr}\frac{ty_{rf}}{y} + b_{Mc}\frac{ty_{cv}}{y} + b_{Moth}\frac{ty_{Mth}}{y}\right] + b_t \alpha_M t y^{-1}$$

$$+ \beta_M\left[b_{rr}\frac{y_{rf}^2}{y} + b_{cc}\frac{y_{cv}^2}{y} + b_{othoth}\frac{y_{oth}^2}{y} + 2b_{rc}\frac{y_{cv}y_{rf}}{y} + 2b_{roth}\frac{y_{rf}y_{oth}}{y}\right.$$

$$\left. + 2b_{coth}\frac{y_{cv}y_{oth}}{y}\right] + b_{tt}\gamma_M t^2 + b_{aa}\pi_M \bar{A} + b_{engeng}\emptyset_M \bar{E}$$

Equation 21

$$d_{ng} = \frac{1}{2}\left[b_{ngng} + b_{ong}\left(\frac{w_o}{w_{ng}}\right)^{\frac{1}{2}} + b_{ngM}\left(\frac{w_M}{w_{ng}}\right)^{\frac{1}{2}} + b_{eng}\left(\frac{w_e}{w_{ng}}\right)^{\frac{1}{2}} + b_{lng}\left(\frac{w_l}{w_{ng}}\right)^{\frac{1}{2}}\right]$$

$$+ b_{ng}y^{-1} + \left[b_{ngr}\frac{ty_{rf}}{y} + b_{ngc}\frac{ty_{cv}}{y} + b_{ngoth}\frac{ty_{ngth}}{y}\right] + b_t \alpha_{ng} t y^{-1}$$

$$+ \beta_{ng}\left[b_{rr}\frac{y_{rf}^2}{y} + b_{cc}\frac{y_{cv}^2}{y} + b_{othoth}\frac{y_{oth}^2}{y} + 2b_{rc}\frac{y_{cv}y_{rf}}{y} + 2b_{roth}\frac{y_{rf}y_{oth}}{y}\right.$$

$$\left. + 2b_{coth}\frac{y_{cv}y_{oth}}{y}\right] + b_{tt}\gamma_{ng} t^2 + b_{aa}\pi_{ng} \bar{A} + b_{engeng}\emptyset_{ng} \bar{E}$$

Equation 22

$$d_l = \frac{1}{2}\left[b_{ll} + b_{lo}\left(\frac{w_o}{w_l}\right)^{\frac{1}{2}} + b_{lM}\left(\frac{w_M}{w_l}\right)^{\frac{1}{2}} + b_{le}\left(\frac{w_e}{w_l}\right)^{\frac{1}{2}} + b_{lng}\left(\frac{w_n g}{w_l}\right)^{\frac{1}{2}}\right] + b_l y^{-1}$$
$$+ \left[b_{lr}\frac{ty_{rf}}{y} + b_{lc}\frac{ty_{cv}}{y} + b_{loth}\frac{ty_{loth}}{y}\right] + b_t\alpha_l t y^{-1}$$
$$+ \beta_l\left[b_{rr}\frac{y_{rf}^2}{y} + b_{cc}\frac{y_{cv}^2}{y} + b_{othoth}\frac{y_{oth}^2}{y} + 2b_{rc}\frac{y_{cv}y_{rf}}{y} + 2b_{roth}\frac{y_{rf}y_{oth}}{y}\right.$$
$$\left. + 2b_{coth}\frac{y_{cv}y_{oth}}{y}\right] + b_{tt}\gamma_l t^2 + b_{aa}\pi_l\bar{A} + b_{engeng}\emptyset_l\bar{E}$$

Appendix 2. Parameter Estimates for the Multiproduct Leontief Cost Function with Quasi-Fixed Inputs

Parameter	Oil	Ethanol	MTBE	Ng	Labor
βoo	2.534.782 (0.6757)				
βeo	-0.00032 (0.000558)				
βmo	0.001744 (0.000688)				
βngo	0.00183 (0.000704)				
βee		-0.1776 (0.2189)			
βme		-0.00161 (0.00147)			
βnge		0.00346 (0.00169)			
βle		0.000478 (0.00271)			
βmm			0.471181 (0.3682)		

Parameter	Oil	Ethanol	MTBE	Ng	Labor
βnn				1.516.189 (0.6163)	
βll					-586.297 -45.109
βngm			-0.00685 (0.00264)		
βlm			0.002747 (0.00233)		
βlng				-0.00508 (0.00316)	
βorf	2,45E-03 (0.000019)				
βocv	-0.00002 (0.000017)				
βooth	-5.06E-6 (0.000011)				
βorfcv	-2.46E-6 (0.000015)				
βorfoth	-3.63E-6 (0.000014)				
βocvoth	8,15E-03 (0.000014)				
βerf		0.000269 (0.000125)			
βecv		0.000373 (0.000121)			
βeoth		0.000254 (0.000079)			
βerfcv		0.000338 (0.000106)			
βerfoth		-0.00027 (0.000095)			
βecvoth		-0.0003 (0.000096)			

Continue

Parameter	Oil	Ethanol	MTBE	Ng	Labor
βmrf			-0.00023 (0.000109)		
βmcv			-0.00016 (0.000105)		
βmoth			-0.00016 (0.000069)		
βmrfcv			-0.00025 (0.000092)		
βmrfoth			0.000213 (0.000083)		
βmcvoth			0.000151 (0.000083)		
βngrf				0.000156 (0.000127)	
βngcv				0.000412 (0.000121)	
βngoth				0.00024 (0.000080)	
βngrfcv				0.000294 (0.000107)	
βngrfoth				-0.00025 (0.000096)	
βngcvoth				-0.00034 (0.000097)	
βlrf					0.000029 (0.000063)
βlcv					-0.00003 (0.000061)
βloth					-6.34E-6 (0.000040)
βlrfcv					0,005846 (0.000054)
βlrfoth					-4.09E-6 (0.000048)

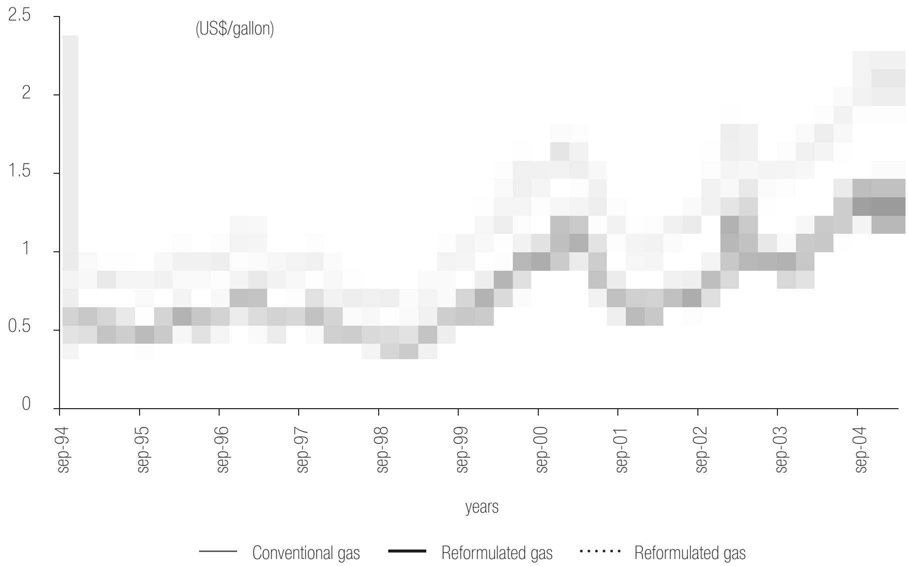
Parameter	Oil	Ethanol	MTBE	Ng	Labor
βlcvoth					0.000026 (0.000049)
βo	-99.1027 (84.8319)				
βe		0.916421 (3.8071)			
βm			-7.86205 (8.7473)		
βn				-49.2241 (19.9982)	
βl					167.2847 (104.7)
ao	0.000011 (6.875E-6)				
ae		2.316E-6 (2.092E-7)			
am			-2.73E-6 (4.867E-7)		
ang				1.18E-6 (1.137E-6)	
al					-6.86E-6 (5.734E-6)
eo	2.22E-14 (1.69E-14)				
ee		-508E-18 (4.33E-16)			
em			5.18E-16 (1.01E-15)		
eng				5.75E-16 (2.36E-15)	
el					-779E-17 (1.25E-14)
Demand Equation	Adj R2	Durbin Watson			

Continue

Parameter	Oil	Ethanol	MTBE	Ng	Labor
DOIL	0.3685	1.97			
DETHANOL	0.9835	1.31			
DM	0.8657	1.92			
DNG	0.7923	1.15			
DL	0.8246	2.78			

Source: Own elaboration.

Appendix 3. Marginal Costs



Source: Own elaboration.