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Efficiency and performance in gas distribution. Evidence from Brazil

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Abstract

The aim of this paper is to analyze the current state of the gas distribution industry in Brazil, by identifying the main factors that determine its performance. To achieve our goal, we evaluate the technical efficiency of firms in the period 2001-2009. The behavior of companies and their regulation by type of ownership, the maturity of the industry, and the network investments level are fundamental issues for the design of energy policy in Brazil. We show that the rate of investment is a necessary condition to allow market diversification, and this strategy contributes to increase companies' technical efficiency. Moreover, the private ownership and price cap regulation are most efficient in relation to public ownership and traditional cost of service regulation. These three findings are important to support the improvement of the regulation of gas distribution at the Brazilian states. The results of this work may be useful for energy policy in those countries considering the introduction of natural gas for final energy consumption.

Key words: Brazilian gas distribution industry, efficiency, parametric distance function
JEL codes: L33, L95

1. - INTRODUCTION

Natural gas has become increasingly important as an energy resource. Liberalization in most parts of the world, restructuring of supply chain, and falling transportation costs, especially for liquefied natural gas, have pushed the emergence of a new "international natural gas market". Significant policy and regulatory reforms have affected the natural gas industry (NGI) since mid-1980s, including the privatization, liberalization, and deregulation of national gas markets, as well as the reduction of trade barriers within important multinational groupings. The driving forces behind reform, however, have considerably differed between developed and developing countries.

In developed countries, the objective of the market-oriented reforms and private ownership is to promote efficiency. Natural gas distribution is part of the so-called network utilities, where the nature of public service and the condition of natural monopoly at local level give rise to a delicate regulation and ownership mode questions (Fabbri et al. 2000). The most important structural reform in gas distribution is the unbundling of different industry segments. Therefore, the main idea is to introduce competition into the wholesale market and retail markets, and to have a regulated monopoly in the transmission and distribution sectors. Thus, the unbundling has allowed a large number of companies dedicated to the natural gas distribution operating in different geographical areas.[1]

The results of different empirical contributions related to the role of ownership mode on firm's efficiency are not unanimous.[2] Additionally, the predominance of public or private firms depends on the country. Both the subjects of market structure and

[1] The condition of natural monopoly implies that firms do not compete in the same geographical area.

[2] Most studies show a slightly higher total efficiency than public firms [Hollas and Stansell (1988, 1994) or Fabbri et al. (2000)]. However, Millward and Ward (1987) do not detect any particular differences in performance.

regulation are connected. In terms of economic regulatory improvements, as Jamasb et al. (2008) point out, most European countries moved towards incentive regulation in transmission, which is complemented by market integration in gas distribution. Meanwhile, in the US the long-standing regime of cost-plus regulation was complemented by increasing pipe-to-pipe competition. As the results of these reforms are uncertain,[3] the concern has been expressed to whether these changes have led to improved industry performance in terms of resource utilization.

In developing countries, the main policy objective is to increase the rate of private investment, by reducing the direct financial involvement in the public sector. Furthermore, one of the main obstacles to the expansion of the natural gas market is the relatively low-level of investments in the distribution network. It is a necessary condition for increasing the gas sales (scale operation) and market diversification. Thus, it is essential to identify the circumstances when private monopolies can finance themselves or direct public intervention is necessary.

The Economic theory has not been able to explain all the reforms outcomes, since the reform success deeply depends on how the sector has been structured and regulated. Therefore, in order to enhance our understanding of the reforms, it is useful to examine and compare existing experiences and evidences of the performance and determinants regarding reforms (Kim et al., 1999). Performance analysis has emerged as a powerful tool to assess the structure of the NGI and to help firms and regulators to understand the productivity and efficiency determinants.[4] Although there have been several studies

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[3] Jamasb et al. (2008) highlight the effect of regulatory change in US transmission companies. It has shown that technical efficiency decreased after well-head price deregulation in 1978, due to increasing prices and falling consumption (Sickles and Streitwieser, 1991), and that the regulatory change requiring third-party access in the mid-1980s led to small reductions in average cost and diverging performance (Granderson, 2000).

[4] The evaluation of efficiency and the establishment of benchmarks serve essentially as performance indicators for distribution companies. In the case of incentive-based approaches, regulator could use this information to induce efficiency performance (Farsi et al., 2007). The electricity distribution industry is a useful example to illustrate the

concerning the efficiency and productivity in the natural gas distribution industry,[5] few studies have focused on developing countries, where the sector is in an immature stage.[6] By studying the gas distribution in Brazil, we are contributing to this process.

The circumstances of the Brazilian industry and their analyses are relevant for several reasons. First, natural gas industry is still underdeveloped. Second, the relatively low-level of investments in the distribution network is an important obstacle for the expansion of the natural gas market. Third, one of the reasons for the low-level of investments in gas distribution is that the Brazilian states do not have the financial resources to make the necessary investments.[7] Forth, even though this industry development is far from its mature stage, it has undergone a reform process.[8] The distribution segment was unbundled and became subject to a regulation that depends on the ownership structure of the companies. Finally, the findings of this paper may be useful for energy policy in countries considering the introduction of natural gas for final energy consumption.

The aim of this paper is to analyze the current stage of the gas distribution industry in Brazil, by identifying the main factors that determine its performance. To achieve our goal, we evaluate the technical efficiency of firms[9] in the period 2001-2009. This

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results of regulatory reforms in network industries for different countries [See Jamasb and Pollitt (2003) in Europe and Ramos-Real et al. (2009) and Tovar et al. (2011) for Brazil].

5 Farsi et al. (2007), in the scarce literature, present a review of econometrics estimation of cost and production functions in gas distribution.

6 Some exceptions are Silveyra and Legey (2007) for Brazil or Ertük and Türut-Asik (2011) for Turkey

7 As will be seen in 3.2, the Brazil Federal Government is in charge of regulating the upstream and the natural gas transportation. However, the State governments are responsible for the regulation of the natural gas distribution.

8 The discovery of large natural gas reserves both in Brazil and neighboring countries has fostered a market-oriented reform of the Brazilian NGI. In 1997, an independent regulator [National Petroleum Agency (ANP)] was established for both oil and gas.

9 Technical efficiency is measured as the ratio between the observed output and the maximum output, under the assumption of fixed input, or, alternatively, as the ratio between the observed input and the minimum input under the assumption of fixed output. In contrast, allocative (or price) efficiency refers to the ability to combine inputs and outputs in optimal proportions in the light of prevailing prices, and it is measured in terms of behavioral goal of the production unit.

analysis attempts not only to identify the determinants of firms' efficiency, but also to analyze the significance of these results for policy-making. The behavior of companies and their regulation by type of ownership, the maturity of the industry, and the network investments level are fundamental issues for the design of energy policy in Brazil. These issues will be discussed along this work.

In this paper, we have proposed the methodology of Batesse and Coelli (1995) because it formulates a specific model to analyze technical inefficiency in terms of appropriate explanatory variables. The model consists of two equations: the first one characterizes the technology (frontier) and let us to estimate the inefficiency level of firms, and the second one, the inefficient model, contains the set of observable explanatory variables associated with the firm's technical efficiency. The estimation of both equations allows us to discover the efficiency drivers we are looking for.

In order to estimate the model, a flexible functional form must be chosen for the first equation. We have chosen a distance function since it presents several advantages as we will see in section 4.2. So, a stochastic multi-output distance function for panel data on Brazilian gas distribution firms is estimated. In addition, from the proposed model, we can obtain important technological information (such as economies of scale and economies of density) and to test whether some factors, as ownership mode, load factor, consumer density, among others, have impacted on the performance of this industry.

The paper has been organized as follows: The second section discusses the characteristics of the natural gas distribution industry. We also briefly review the literature about performance analysis in gas distribution. The third section shortly introduces the regulatory framework of the Brazilian gas distribution, by covering both 1990s restructuring process and current situation. The fourth section shows the methodology employed to estimate an efficient frontier in a multi-output and multi-input framework. The fifth section describes the data. The sixth one shows the variables and the empirical results. Finally, the last section displays the main findings of this paper.

2. - THE FEATURES OF THE GAS DISTRIBUTION INDUSTRY

In this section we will discuss the main characteristics of the natural gas distribution industry and review the most important empirical results in the literature. This analysis is crucial for understanding the choice of variables in section 5.2 and for comparison purposes . Our gas analysis begins with its entry into the bulk transmission system, through the local distribution networks, to the final consumers for many purposes: industrial, automotive, commercial, residential, and thermopower generation. As other network industries, gas distribution is a capital-intensive activity that exhibits some specific features that characterize the industry as a natural monopoly.[10] Guldman (1985) evaluated the consequences of alternative market forms characterized by competition. He showed that several utilities operating competitively in the same area seems to be disadvantageous.

Hawdon (2003) highlights three important facts that determine the performance analysis of this industry. First, an industry which has economic goals in terms of reducing the cost of supplying gas, together with the social goal of extending access as far as possible, can be readily described in terms of multi-output, multi-input production theory. Second, very little data exist on the finer qualities of gas delivery systems, which are the problem to assess their significance for performance evaluation. Third, the environment in which the gas industry functions considerably varies among countries,

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[10] Silveyra and Legey (2007) highlight the following: the indivisibility of the equipment; the extended constructions times and long periods for investment return, the high and non-recoverable fixed costs, among others.

in terms of gas transportation, the geographic density of customers, and other socioeconomic characteristics.

For all above and, in order to analyze this industry, it is essential to make a correct definition of the variables describing this activity: outputs, inputs, and environmental variables. The widespread outputs that have been used in the studies conducted on natural gas and electricity distribution companies' efficiency analysis are consumption and number of customers (Farsi et al. 2007). The inclusion of the 'number of customers' as output reflects the spread of demand among the connection points that is generally regarded as a major cost driver. This variable also captures the important differences in average consumption levels, as well as between the regional distribution (Jamasb and Pollitt, 2003). Two major inputs are the labor force involved in the gas industry activities and the capital services of the pipeline system that connects producers to customers.

Some papers have highlighted the importance of accounting for output characteristics in gas distribution. Hollas and Stansell (1988) analyzed this industry by modeling efficiency through a translog profit function in US. They used customer density[11] as environmental variable and gas delivered as output measure. They showed that the total efficiency is slightly higher in private firms than in public firms. Lowry and Getachew (2009) and Bernard et al. (1998) considered the load factor and the network length as major cost drivers that should be included in estimating a translog cost function.[12] Kim

[11] Customer density is a ratio of the number of consumers divided by the service area or network size. The "average customer size" is the average consumption.

[12] The 'size of the network' also reflects the geographical dispersion of the output and the scope of operation. The load factor is defined as the ratio of annual average flow of gas to the annual peak flow per hour. It is a measure of how constantly the network capacity is used throughout the year. A higher value of load factor implies a lower variation in consumption. The load factor is a demand characteristic and cannot be directly influenced by the company. A network with a low load factor requires more capacity.

and Lee (1996) pointed out the inclusion of customer density and average customer size as output characteristics in a translog cost function.

Price and Weyman-Jones (1996) measured technical efficiency for firms between 1977 and 1991 in the UK. They used a nonparametric frontier analysis to calculate Malmquist indices and found that the rate of productivity growth significantly increased after privatization. Fabbri et al (2000) estimated a total distribution translog cost function for Italian companies. Their results suggest a more cost efficient production in private firms. Farsi et al. (2007) estimated a stochastic frontier cost function by using different panel data models of gas distribution in Switzerland from 1996 to 2000. The results show an average inefficiency of about 7% in the sector. These two previous papers found a common finding of several studies performed in other countries that is the evidence of considerable density economies, but insignificant or weak scale economies in gas distribution industry. Rossi (2001) estimated a stochastic frontier production function, by using the approach of Batesse and Coelli (1992), to analyze the technical change in the post-privatization period in the gas distribution industry in Argentina. He found both a catching up effect and a shift in the frontier, which show that the sector improved its efficiency in this period.

The gas industries in emerging countries are of concern to some papers. Silveyra and Legey (2007), for Brazil, and Ertük and Türut-Asik (2011), for Turkey, find out that an important source of inefficiency is related to the scale of operation for gas distribution companies. The most important finding of the latter is that most of the firms in the Turkish natural gas distribution sector are immature, and it is too early to draw up a conclusion about the inefficiency.

3. BACKGROUND

3.1. Brazilian Gas Distribution Industry

Brazil currently has 22 distribution companies operating in 21 states[13]. The distribution infrastructure is heavily concentrated in the two major consuming states, Rio de Janeiro and São Paulo, where over 73% of the country's distribution pipeline infrastructure is located. Table 1 shows the profile of main distribution companies in Brazil.

Table 1 – Profile of Distribution Companies Operating in Brazil (2009)

	Cities in Concession	Cities Attended	Clients (Number)	Sales (000 m^3/day)	Size of Pipeline (Network Km)
Algas	102	9	3,179	497.27	234
Ceg	20	18	735,750	8,462.27	3,971
Ceg Rio	72	14	21,537	9,144.76	838
Cegas	184	11	259	509.85	264
Bahiagas	417	12	277	3,509.22	552
Msgas	78	2	67	279.00	152
Gasmig	853	23	247	2,451.05	356
Pbgas	250	7	86	383.24	248
Compagas	399	8	4,795	1,365.92	499
Copergas	185	13	197	1,158.48	397
Potigas	167	8	117	403.10	280
Sulgas	467	16	571	1,749.31	473
Scgas	293	34	1,037	1,579.38	769
Comgas	177	44	639,015	14,317.42	5,704
GN SP Sul	93	17	31,691	1,362.81	1,267
Sergipegas	75	5	4,280	291.08	136

Source: ABEGAS and companies annual report

[13] Brazil is composed of 26 states and 1 federal district. Technically, 27 distribution companies exist in the country, but 8 are not operating yet.

Figure 1 – Map of the Concession Areas of the Gas Distribution companies in Brazil

Source: Abegas

The distribution network in Brazil is very underdeveloped. Currently, there are about 19,400 km of distribution pipeline. Comgas in São Paulo and Ceg in Rio de Janeiro are the only companies with large distribution networks. They are also the only gas distributors in Brazil with a significant number of clients in the residential and commercial sectors (see Table 1). All the other distribution companies are focused on the large volume gas markets (power plants and heavy industry). São Paulo is, by far, the largest natural gas consumer, followed by Rio de Janeiro and Bahia, respectively.

The private sector controls the largest distribution companies in Brazil: Ceg (Rio de Janeiro) and Comgas (São Paulo). The five distribution companies in Rio de Janeiro and São Paulo states are privately-owned, with BG, Shell, ENI[14], and Spain's Gas Natural among the major stockholders. The 19 remaining companies in Brazil are mixed capital companies, with the state government owning, in many cases, 51% of the shares. In

[14] In 2010, Petrobras acquired ENI's distribution company, located in the western part of São Paulo State.

addition, Gas Natural SPG and Gas Brasiliano (all in São Paulo) are also privately-owned. Though differing from state to state, on average, public-owned gas distribution companies are controlled by state governments (51% of the shares) and, generally, Petrobras and private companies hold 25% and 24% of the shares, respectively[15](see Table 2). Petrobras has an important role in the management of the state-owned distribution companies: to be the sole natural gas supplier to the distribution companies and to be responsible for gas marketing policy in the distribution companies they hold shares.[16]

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15 Some distribution companies are indirectly controlled by the state governments. Gasmig, from the state of Minas Gerais, and Compagas, from the state of Paraná, are controlled by their state-owned power companies, Cemig and Copel. Petrobras wholly controls the distribution company in the state of Espírito Santo.

16 It is important to note that Petrobras is the sole gas supplier to the distribution companies in Brazil. Even though gas exploration and production is not legal monopoly of Petrobras, most of natural gas is produced by the company. Gas produced by other companies is generally sold to Petrobras at the wellhead. Therefore, all distribution companies are supplied by Petrobras in similar commercial condition.

Table 2 - Patrimonial Structure of the Gas Distribution Companies – 2009*

Firms	Petrobras %	State %	Private companies %
ALGAS	24.5	51	24.5
BAHIAGAS	24.5	51	24.5
CEGAS	24.5	51	24.5
COPERGAS	24.5	51	24.5
EMSERGAS	24.5	51	24.5
PBGAS	24.5	51	24.5
POTIGAS	49	51	0
GASPISA	24	51	24.5
GASMAR	23.5	25.5	51
GASMIG	40	60	0
CEG	0	0	100
CEG RIO	26.2	0	73.8
COMGAS	0	0	100
GAS NATURAL SPS	0	0	100
GÁS BRASILIANO	0	0	100
BR DISTRIBUIDORA	100	0	0
COMPAGAS	24.5	51	24.5
SULGAS	49	51	0
SCGAS	23	51	26
MSGAS	49	51	0
GOIASGAS	30	51	19
CEBGAS	32	0	68
RONGAS	24.5	51	24.5
CIGAS	0	100	0

Source. Petrobras 2010. *Such information was available on the Petrobras website in 2010.

3.2. The regulation of the Brazilian gas distribution segment

Until recently, there was no clear specific regulation for the Brazilian NGI.[17] The main specificity of the Brazilian NGI is the fact that Federal and State governments are responsible for the regulation. While the Federal Government is in charge of regulating the upstream and the natural gas transportation to the city-gates, the Brazilian states regulate the natural gas distribution. Natural gas is the single case in the Brazilian energy industry whose part of the regulation is in charge of the states. All other energy industries are regulated by federal regulatory agencies.[18]

Most of the states adopted the same model for the distribution sector in the early 1990s, by offering similar concession agreements and patrimonial structures. The public-owned firms' concession agreements were executed before the passage of the oil and gas Act 9,478 in 1997. This contract hinders the introduction of a market-oriented regulatory framework in the distribution segment. First of all, contracts were executed directly by the state governments, for there were no state regulatory agencies at that moment. This represented an obstacle for the establishment of independent regulatory agencies in the states for the gas sector, because there were no provisions concerning the agencies' role in those concession agreements.

Another important characteristic of the concession agreement of the public-owned distribution companies is the granting of territorial monopolies for the entire period of the concession (fifty years). Therefore, there are no provisions concerning the

[17] Petrobras, a state-owned company, had monopoly rights for both oil and gas production, imports, and transportation and acted as the industry regulator. Retailing was competitively done in the case of oil products, while gas had been supplied by provincial state-owned companies only to small areas of Rio de Janeiro and São Paulo.

[18] Currently, 17 Brazilian states have established their regulatory agencies. Where there is no regulatory agency, the state Energy Secretary is in charge of executing concession agreements with the distribution companies and regulating the sector. In general, regulatory agencies are responsible for regulating the gas distribution.

introduction of open-access to the grid in the long run. A traditional cost-of-service tariff scheme was adopted. Therefore, the gas costs are automatically passed on to final prices and tariff adjustments are made annually or when necessary to guarantee companies' financial equilibrium.[19]

Five distribution companies in the states of Rio de Janeiro (Ceg and Ceg-Rio) and São Paulo (Comgas, Gas Brasiliano, Gas Natural Sul) follow a different regulatory framework. These companies have executed a new concession agreement following their privatization, after the passing of Act 9,478 in 1997. The main characteristics of the concession agreements executed with the privatized companies are: i) market exclusivity is guaranteed only for part of the concession period (10 to 12 years). After this period, third parties are permitted to supply large consumers; ii) final gas tariff is fixed by the "price-cap" system in order to induce efficiency; iii) a tariff revision every five years and tariff realignment every year according to the wholesale price index; and iv) the period of the concession is limited to 30 years.

The contracts of São Paulo's distribution companies contain provisions establishing a minimum level of investments for the first 10 years. Additionally, distribution companies are obliged to expand the network when economically feasible. Should the project be not economical, end-users have the right to participate financially in the project in order to make it viable.

One of the main obstacles for the expansion of the natural gas market in Brazil has been the relatively low-level of investments in the distribution network. In general, the expansion of the distribution network is a necessary condition for increasing the gas sales. One of the reasons for the low-level of investments in the gas distribution

[19] The contract guarantees a 20% yield on the companies' own capital. There are no obligations concerning minimal investment rates. These companies have to consider projects with 20% rate of return only.

segment has been the patrimonial structure of the distribution companies not yet privatized. The problem with these companies is the fact that, in general, the States do not have the financial resources to make the necessary investments.[20]

4. METHODOLOGY

In the first two sections we have analyzed the characteristics and the structure of natural gas industry in Brazil. In this section we will introduce the model employed to analyze the technical inefficiency in terms of appropriate explanatory variables. Such model allows us to obtain important technological information and to check the factors that have impacted on the performance of this industry.

4.1. The efficient frontier method

Farell (1957) proposed the idea of estimating an efficient frontier against which the performance of different production units could be measured. He also defined the efficient production frontier as the maximum quantity of output that can be obtained from a given set of inputs. Since then, several lines of research have been developed in the field of efficiency analysis, and this paper belongs to those that attempt to explain the causes of inefficiency by using parametric estimations of the stochastic frontier.[21]

Early empirical studies that address this issue include, among others, Pitt and Lee (1981) and Kalirajan (1990). These authors used a two-stage methodology, where they firstly obtained estimates of technical inefficiency. They then attempted to determine

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[20] The electricity crisis in Brazil in 2001 changed financing policy of the Brazilian Development Bank (BNDES). BNDES was once again permitted to finance projects of state-owned companies and as a result several projects in the distribution sector are underway. Nevertheless, the state-owned companies still have trouble to get financing in international credit markets. Additionally, these companies have difficulty for obtaining financing in the domestic market. For a long time, BNDES has not financed state-owned companies. Therefore, the state-owned distribution companies have had a limited investment capacity.

[21] Both nonparametric and parametric efficiency measurements are used by applied literature (see Lovell, 1993). In this paper, we have chosen a parametric method of Batesse and Coelli (1995), because it is a consistent way to model the inefficiency and analyze its drivers.

the causes of this in a second stage, through regression, where inefficiency in different industries was explained by a vector of firm-specific characteristics, including size, age, and type of ownership. These early two-stage models had problems of consistency.[22] This gave rise to other methodological proposals, such as the models of Kumbhakar et al. (1991) and Reifschneider and Stevenson (1991), whereby the inefficiencies were expressed as an explicit function of a vector firm-specific variables and a random error. Huang and Liu (1994) developed a model where inefficiencies depend on both firm-specific factors, as well as the interactions between these firm-specific factors and the production inputs of the stochastic frontier.

Battesse and Coelli (1995)[23] proposed a model similar to that of Kumbhakar et al. (1991), except that they imposed allocative efficiency. This permitted time variation in the estimated inefficiencies and the use of panel data. This model can be expressed as:

$$\hat{y}_{it} = \exp(\alpha + x_{it}\beta + v_{it} - u_{it}) \qquad (1)$$
$$with \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T$$

which is the first equation and where y_{it} is the production of firm i in period t, x_{it} is the vector of inputs used by firm i in period t, α is the constant, and β is a vector of unknown parameters to be estimated. The components of the error term, v_{it} and u_{it}, represent statistical noise and technical inefficiency respectively.

In the Battesse and Coelli (1995) model, v_{it} represents random disturbances, which are assumed to be i.i.d. errors, distributed as $N(0,\sigma_{\omega}^2)$, and independent of the technical inefficiencies u_{it}, which is a non-negative random variable, which captures the effects of technical inefficiency on production; and it is assumed to be independently

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22 In the first stage, the inefficiencies are assumed to be i.i.d. errors, whereas in the second stage they are considered to be specific to the firm.

23 In this model, the parameters that potentially influence the level of technical efficiency are jointly estimated along with the changes over time of technical efficiency and technical change. This allows us to maintain the assumption that the factors affecting technical efficiency are independently distributed.

distributed according to the distribution $N(\zeta_{\iota\tau}\delta,\sigma_{\upsilon}^{2})$, which is truncated at zero. Z_{it} is the vector that contains the set of observable explanatory variables associated with the firm's technical efficiency, and δ is a vector of parameters to be estimated. Thus, technical inefficiency model, which is the second equation, can be expressed as:

$$u_{it} = \delta_0 + Z_{it}\delta + W_{it} \qquad (2)$$
$$with \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T$$

In this way, the mean values of the corresponding truncated normal distributions are not identical for all units, although they are functions of the same variables and parameters. This set-up allows us to recover the technical efficiency of the i^{th} unit in period t from the expression:

$$ET_{it} = \exp(-u_{it}) \qquad (3)$$
$$with \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T$$

4.2. The model

In this paper, we use the model proposed by Battesse and Coelli (1995) with two slight variations. The first one, in order to take into account the unobserved firm specific heterogeneity,[24] we propose estimate the model within a *fixed effect model* (FEM)[25] framework by introducing firms dummy variables into the production function to capture unobservable heterogeneity.[26] The second one is that; instead of using a production function, we will use a distance function as it has certain advantages.

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24 A number of studies criticized model proposed by Battese and Coelli (1995) and refused their use in network industries with strong unobserved heterogeneity (see Greene, 2005 and Farsi et al, 2005, among others). The problem is that model of Battese and Coelli (1995) analyzes the data as a pooled data. If there is heterogeneity among firms and it is not explicitly picked up in the model, a problem of omitted variables will exist, and the estimated coefficients of the included variables will be biased.

25 Nevertheless, to see the validity of the fixed-effects model, we conducted a Hausman test. We get a *chi2(13)= 23.33, prob>Chi2= 0.0379* so the Hausman test statistic indicated that the null hypothesis could be rejected at the *5 %* level of significance. Therefore, we conclude that the preferred model is fixed effects.

26 The main advantage of using a panel data model instead of a pooled is that it is possible to capture the unobservable systematic differences between firms.

Distance functions describe a multi-input, multi-output production technology, without making behavioral assumption, such as cost minimization or profit maximization. This is especially suitable for regulated industries. Another important advantage of distance functions is that input and output prices are not needed. The distance function can take an input orientation or an output orientation. In this paper, we follow an input-oriented approach because it represents the behavior of companies regarding the decision related to the quantity of inputs to be used, by considering that a determined demand of goods or services needs to be met (see Thanassoulis, 2002, and Pombo and Taborda, 2006). Thus, this type of orientation better represents the gas public service provision, in which the companies must meet a determined exogenous demand for the concession of distribution in a specific geographic area.

An input distance function characterizes the production technology, by looking at a maximum proportional contraction of the input vector for a given output vector:

$$D_i(y_{it}, x_{it}) = Max \quad \mu \quad \left[\mu \geq 1 : T\left(y_{it}, x_{it} / \mu\right) = 0\right] \tag{4}$$

$$with \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T$$

where μ is the largest scalar by which the input vector x_{it} can be deflated to, so that the resulting vector of deflated inputs (x_{it}/μ) and the vector of outputs (y_{it}) are on the frontier. The distance function takes the value 1, when the firm is efficient and is therefore on the frontier; and it takes values between 0 and 1, when the firm is inefficient. In a parametric context, input distance function can be expressed as:

$$1 = D_i(y_{it}, x_{it}, T; \alpha, \beta, \psi, \gamma, \rho, \theta) \exp(v_{it} + u_{it}) \tag{5}$$

$$with \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T$$

where D_i (y_{it},x_{it},T) is the input distance function, y is a vector of outputs, x is a vector of inputs, T is a time trend, i relates to the i^{th} firm, and $\alpha, \beta, \psi, \gamma, \rho, \theta$ are parameters to be estimated. Lastly, v_{it} and u_{it} are disturbance terms, which have already been defined.

4.3. Econometric Specification

The empirical application of a parametric distance function calls for the definition of an appropriate functional form. The desired functional form should present the following advantages: it must be flexible,[27] it must be easy to calculate, and it must allow for the imposition of the homogeneity condition. We have chosen the translogarithmic functional form because it meets these conditions.

In order to determine the frontier, D_i needs to be equal to the unit; this being the case, the term on the left of equation 1 will equal zero, according to the Neperian logarithm. Consequently, inputs must meet the homogeneity condition of degree 1. According to Lovell et al. (1994)[28], this condition has been imposed by normalizing the distance function with one of the inputs. In a translogarithmic distance function, any input can be chosen, say x_{mit}, resulting the following expression:

$$\ln(D_i / x_{nit}) = TL(y_{it}, x_{it} / x_{nit}, T; \alpha, \beta, \psi, \gamma, \rho, \theta) \quad \text{with} \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T \tag{6}$$

Finally, the following expression is obtained:

$$-\ln(x_{ni}) = TL(y_{it}, x_{it} / x_{ni}, T; \alpha, \beta, \psi, \gamma, \rho, \theta) - \ln(D_i) \quad \text{with} \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T \tag{7}$$

---

27 This is in order to weaken as much as possible the implications of assuming a particular functional form for the underlying input distance function.

28 This methodology has been applied in various empirical papers; see Coelli and Perelman (1999, 2000); Morrison et al. (2000); Orea (2002); Trujillo and Tovar (2007); Tovar and Rendeiro Martin-Cejas (2009); and Pérez-Reyes, R. and Tovar, B., (2010), among others.

In Equation 7 $-ln(D_i)$ is non-observable, and can be interpreted as an error term. Equation 7 may be estimated by the maximum likelihood, following the stochastic frontier approach proposed by Aigner et al. (1977). If we replace $-ln(D_i)$ by a composed error term $(v_{it} - u_{it,})$, where v_{it} and u_{it} represent statistical noise and technical inefficiency respectively. When applied to the distance function this yields:

$$-\ln(x_{ni}) = TL(y_{it}, x_{it}/x_{ni}, T; \alpha, \beta, \psi, \gamma, \rho, \theta) + v_{it} - u_{it} \quad \text{with} \quad i = 1, 2, ..., N \; ; t = 1, 2, ..., T \tag{8}$$

The distance function value may be estimated as:

$$D_{it} = E\left[\exp(u_{it}) / e_{it}\right] \quad \text{where} \quad e_{it} = v_{it} - u_{it} \tag{9}$$

5. DATA AND VARIABLES

5.1. The equations

The data set consists of a balanced panel of 15 Brazilian gas distributions over 9 years (2001-2009). The data set was constructed on the basis of the companies' annual reports and balance sheets. They were complemented by information provided by Brazilian Association of Gas Distribution Companies (ABEGAS). The firms covered by the sample were: Algas, Bahiagas, Ceg, Ceg Rio, Comgas, Compagas, Copergas, Gas Brasiliano, Gas Natural SPS, Gasmig, Msgas, Pbgas, Scgas, Sergas, and Sulgas. These companies delivered about 92% of Brazilian gas consumption in 2010.

Our analysis is related to the gas distribution networks to the final consumers. The data available determine the framework within which important features of the operation of distribution utilities can be modeled. With the data gathered, we have estimated a model that is formed by two equations. The first one is the following stochastic translogarithmic input distance function:

$$
-\ln\left(x_{nit}\right) = \alpha_0 + \sum_{i}^{m} \alpha_i \ln y_{it} + \sum_{i}^{n-1} \beta_i \ln x_{it}^{*} + \frac{1}{2} \sum_{i}^{m} \sum_{j}^{m} \psi_{ij} \ln y_{it} \ln y_{jt} +
$$

$$
\frac{1}{2} \sum_{i}^{n-1} \sum_{j}^{n-1} \gamma_{ij} \ln x_{it}^{*} \ln x_{jt}^{*} + \sum_{i}^{m} \sum_{j}^{n-1} \rho_{ij} \ln y_{it} \ln x_{jt}^{*} + \sum_{i=1}^{14} \lambda_i D_i + v_{it} - u_{it}; \quad (10)
$$

$$
with \quad x_{it}^{*} = x_{it} / x_{nit}
$$

Where: i relates to the i^{st} firm, α, β, ψ, γ, ρ and λ are the coefficients to be estimated, Di is a dummy variable for the distribution company *i; l*v_{it} is a symmetrical error term, *i.i.d.* has a zero average that represents the random variables that cannot be controlled by the firm, and u_i is a one-sided negative error term that measures the technical inefficiency of each operator and is distributed independently of v_{it}. The variables have been divided by the geometric mean. Therefore, the first order coefficients can be interpreted as elasticities at this point, thus the inverse of the sum of the first order coefficients for products represents the return to scale (Atkinson and Primont, 2002).[29]

The second equation allows us to model the effects of technical inefficiency, as a function of the firm-specific variables that we consider may influence a gas distributor's efficiency. The efficiency of natural gas distribution companies is affected by different characteristics of the market. The system formed by the two equations was estimated by maximum likelihood.[30]

5.2. The variables

By choosing the relationship to be estimated, it is necessary to pick up the variables to be included in the analysis. Our specific choice of variables is in accordance with the general consensus found in the current literature (see section 2).

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29 This is due to the dual relationships between the cost function and the distance function.

30 The estimation was made by Stata version 11.

For the outputs, we consider two measures: network length and sales.[31] The joint inclusion of network and sales reflects the spread of demand among the connection points. This is an indirect way of taking into account the sales density and the average customer size.[32] We tested the inclusion of other output characteristics variables, but they were not significant.[33]

This study uses monetary values of the input variables[34] and not physical units[35]. As Jamasb and Pollitt (2003) point out, this is particularly advantageous from a regulatory point of view, as monetary values of the inputs can reflect all operating and capital inputs. Three inputs are used: capital costs, cost of sales, and operating costs. With this choice, we consider in a comprehensive manner the different production inputs. Capital cost is measured through the active capital of the period (net fixed assets under exploitation for a given period). Cost of sales accounts for gas purchases and other services sold.[36]

Finally, operating costs represent all the inputs other than capital and cost of sales. We have chosen this variable for two reasons. The first one, and most important, is that we were not able to gather data on labor. The second one was that, in this way, we can avoid problems derived from different firms' outsourcing practices. Time trend was initially included in the first equation (10), but the linear parameter was not statistically significant, by pointing out that there was not technical change in the period.

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31 Some papers as Lowry and Getachew (2009) or Bernard et al. (2002) point out that network length can be treated as an output because is a proxy of the number of connections.

32 See Roberts (1986) and Ramos-Real et al. (2008).

33 We have tested to break the product between residential sales and the rest of sales (medium and big consumers), but the linear parameter of the second output was not statistically significant (even the sign was wrong). We also tried to include the ratio obtained by dividing the large sales by total sales, but the result was similar.

34 As Coelli et al (2003) point out, almost all studies involve the use of at least some value measures.

35 As we have deflated, the input measures are proxies for physical input quantity.

36 Farsi et al. (2007) point out that there are two methodologies upon considering gas purchased. The integrated methodology considers gas purchased as an input and the network operating approach excludes it. The second alternative neglects the potential inefficiencies in the choice of the gas delivery contract.

The second equation allows us to model the effects of technical inefficiency,[37] as a function of the firm-specific variables that we consider may influence a gas distributor's efficiency. The efficiency of natural gas distribution companies is affected by different characteristics of the market. We have tested different variables[38] that may determine the efficiency in this Industry, and finally we have considered the following: density of customers, load factor, ownership, and time trend.

$$
\begin{aligned}
u_{it} &= \delta_0 + \delta_1(Population\ \ density_{it}) + \delta_3(Load\ \ factor_{it}) + \delta_4(ownership_{it}) \\
&+\delta_5(time_{it}) + W_{it} \qquad \text{with} \quad i = 1, 2, ..., N \ ; t = 1, 2, ..., T
\end{aligned}
\tag{11}
$$

The error term in equation (11), W_{it}, is a random variable obtained from the truncation of a normal distribution, where $(- z_{it}\ \delta)$ is the point of truncation.

Due to lack of variable number of customer to calculate consumer density, we have approximated it by the natural log of the ratio population/concession area. The average maintenance cost per customer is lower in networks with higher density. We therefore expect that a higher consumer density leads to a more efficient situation. The load factor, following Farsi et al. (2007), was obtained as the ratio of the monthly average flow of gas to the monthly peak flow each year, also measured in natural log. We expect lower costs for companies with a low load factor.

The ownership dummy takes value 1 for private firms and 0 for public firms, and we expect that private firms show a higher technical efficiency because they faces a more favorable environment. As already noted in section 3, regulation is different for each type of ownership.[39] This regulation establishes investment targets to the private

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[37] The error term in equation (10) has two components: v_{it}, which is a random term, and u_{it} represents economic inefficiency as explained in Section 4.

[38] We consider that the firm's investment level could be an important efficiency driver, but, unfortunately, we could not test it since this data was not available.

[39] We mentioned in section 3 that these companies are: Ceg and Ceg-Rio, in Rio de Janeiro, and Comgas, Gas Brasiliano, and Gas Natural Sul, in São Paulo.

companies, which face fewer restrictions than the public ones, to mobilize capital to invest in their expansion. Finally, the time trend in this equation specifies that inefficiency effects may change linearly with respect to time.[40]

Table 3 below shows a summary of the variables. The results are shown in the following section.

Table 3 – Sample Summary Statistics

Variables		Mean	Standard deviation	Minimum	Maximum
Outputs	Network (km)	880	1,313	49	6,257
	Sales (000 m^3)	894,094	1,110,480	564	5,244,712
Inputs	Capital (Real - dec 09)	312,531,233	518,255,174	6,549,389	2.45E+09
	Cost of sales (Real - dec 09)	406,585,297	538,171,518	15,206,662	2.74E+09
	Operating costs (Real - dec 09)	40,203,449	66,566,934	1,104,160	2.56E+08
Firm specific variables	Density of customer (population/area)	240.33	524.24	6.19	2096.57
	Max Demand	0.78	0.19	0.08	0.96
	Ownership	0.34	0.48	0	1
	Time Trend	7.22	2.52	3	11

40 We have also included a time trend squared to lending flexibility to the effect of time on inefficiency, but it was not statistically significant.

6. DISCUSSION OF RESULTS

6.1. Global estimation results

Firstly, we have analyzed the estimation results of equation (10). Table 4 shows the estimated maximum likelihood parameters from the input distance function. Also, all first order parameters are statistically significant and have the correct sign. This implies that the estimated distance function complies with all expected theoretical properties. The regularity conditions of the sample's mean average have been met; it is non-decreasing and quasi-concave with respect to inputs and decreasing for outputs.

In the mean of variables, the degree of scale economies is 0.9590. It indicates that they have been exhausted, although this value will be different for each firm depending on the production size. For the scale economies, it is assumed that as the production scale increases, all outputs and outputs characteristics vary at the same proportion. Otherwise, in network industries, the output variation has been generally together with a change in output characteristics, such as network size. The concept of density economies has been used to describe this situation. We can obtain a value of sales density economies by calculating the inverse of the first order coefficient for sales (Roberts, 1986). The value of this ratio is 2.5408, which clearly indicates an increase in sales, while maintaining the constant size of the network generates a reduction in the radial average cost. These two findings, as discussed in section 2, are fairly common in the literature.[41]

[41] In general, distribution companies start their operation focusing on investment in the network, to supply large volume clients. These consumers anchor large pipeline projects. After large industrial consumers have been supplied, distribution companies tend to invest in secondary pipelines to supply small volume clients in the household and commercial segments.

Table 4 – Input Distance Function parameter estimates

Variable	Coefficient	Standard.error	z	P>|z|	
Constant	0.3805	0.0560	6.8	0.000	***
Sales	-0.3936	0.0517	-7.61	0.000	***
Network	-0.6491	0.0801	-8.1	0.000	***
Capital	0.3050	0.0415	7.34	0.000	***
Approv.	0.5866	0.0407	14.42	0.000	***
Soft input	0.1084	0.0340	3.19	0.001	***
Sales x Sales	-0.0586	0.0318	-1.84	0.065	*
Network x Network	-0.0531	0.0814	-0.65	0.514	
Sales x Network	0.0597	0.0498	1.2	0.231	
Capital x Capital	0.0643	0.1332	0.48	0.629	
Approv. x Approv.	0.2158	0.0598	3.61	0.000	***
Soft input x Soft input	0.2109	0.0748	2.82	0.005	***
Capital x Approv.	-0.0346	0.0805	-0.43	0.667	
Capital x Soft inputs	-0.0297	0.0876	-0.34	0.735	
Approv. x Soft inputs	-0.1812	0.0433	-4.18	0.000	***
Capital x sales	-0.0282	0.0747	-0.38	0.706	
Capital x Network	0.1618	0.0816	1.98	0.047	**
Approv. x Sales	-0.1456	0.0428	-3.4	0.001	***
Approv. x Customers	0.0065	0.0570	0.11	0.908	
Soft input x Sales	0.1738	0.0621	2.8	0.005	***
Soft input x Customers	-0.1684	0.0668	-2.52	0.012	**
D2	-0.0319	0.1988	-0.16	0.872	
D3	-0.3236	0.1752	-1.85	0.065	*
D4	-0.3182	0.1123	-2.83	0.005	***
D5	-0.5980	0.1631	-3.67	0.000	***
D6	0.0816	0.1482	0.55	0.582	
D7	-0.1904	0.0995	-1.91	0.056	*
D8	-0.3373	0.0938	-3.6	0.000	***
D9	-0.0243	0.1192	-0.2	0.838	
D10	-0.4753	0.1630	-2.92	0.004	***
D11	0.6500	0.3857	1.69	0.092	*
D12	-0.0581	0.0764	-0.76	0.447	
D13	-0.2065	0.1026	-2.01	0.044	**
D14	-0.0701	0.0526	-1.33	0.183	
D15	0.0243	0.1654	0.15	0.883	

Note Level of significance. * = 0.05 ** = 0.01 *** = 0.001

The inefficient model results (see Table 5) also imply that the level of inefficiency in the Brazilian gas distribution firms sample is explained by the variables considered. The variance parameters, σ^2 and γ, are statistically significant, and the estimated value of parameter γ is close to 1; this shows that for the gas distributors sample analyzed, the effects associated to the inefficiency are more significant than those related to the statistic noise, that is to say, the inefficiency effects are likely to be highly significant in the analysis of the distance function of firms. A negative parameter means that inefficiency decreases if the value of the parameter's variable increases.

Table 5. Inefficiency effect model

Variable	Coefficient	Standard.error	z	P>|z|	
Constant	0.1073	0.0758	1.42	0.157	
Density	-0.3245	0.1372	-2.36	0.018	**
Max demand	-0.3733	0.1305	-2.86	0.004	***
Ownership	-0.3378	0.1356	-2.49	0.013	**
T	-0.0039	0.0140	-0.28	0.781	
/lnsigma2	-3.8252	0.2511	-15.23	0.000	***
/ilgtgamma	3.3485	0.7166	4.67	0.000	***
sigma2	0.0218	0.0055			
Gamma	0.9661	0.0235			
sigma_u2	0.0211	0.0056			
sigma_v2	0.0007	0.0004			

Note Level of significance. * = 0.05 ** = 0.01 *** = 0.001

The coefficients linked to population density and load factor are negative. The first one implies greater efficiency of those companies operating in areas of higher population density. This can be explained because in these areas it is necessary a lower-level investment per customer (same size), by making possible to take advantage of the density economies. It is also important to note that most of large industries are located within large population density. Load factor contributes positively to efficiency; this can be explained by the fact that a more intensive utilization of installed capacity contributes positively to efficiency performance.

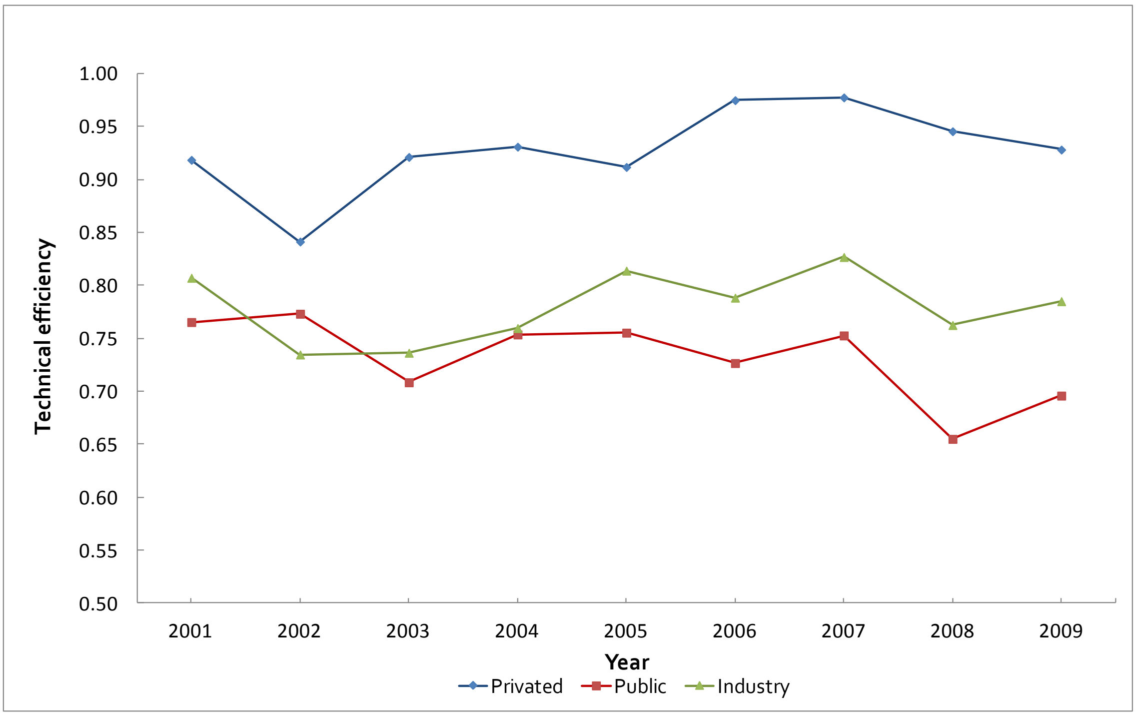
The coefficient linked to property is also negative and statistically significant, implying that public property of the gas distribution company (1 if private, and 0 if public) increases the inefficiency. Thus, we can say that the mode of ownership and the different regulation for private companies have a differential effect on the efficiency of firms. As other works (Fabbri et al. 2000), this result has suggested a more efficient production in private firms in this industry.

Finally, the coefficient linked to time trend is negative - but not statically significant - which means that distribution firm's efficiency improved during the time period under consideration and coincided, as previously stated, with the sector reform process. This result has been consistent with the fact that during this period the average level of industry efficiency has remained fairly stable, as shown below.

Figure 2 has shown the average technical efficiency evolution for Brazilian gas distribution industry in the period, distinguishing also for public[42] and private companies. The industry average evolution ranges from 80.7% to 78.5%, between 2001 and 2009. Figure 2 has shown clearly that, on a yearly basis, average industry technical efficiency has remained fairly stable. This Figure also shows that, in average, private companies have a significantly higher technical efficiency levels (approximately 90% vs. 75%). Moreover, the evolution has been different by comparing public with private companies. While the former has shown a slight decline during the period, the private companies have a slightly favorable evolution, but stabilized in the last three years.

[42] Algas, Bahiagas, Compagas, Copergas, Gasmig, Msgas, Pbgas, Scgas, Sergas, and Sulgas.

Figure 2. Average Technical Efficiency of the Brazilian distribution industry by year (2001-2009)



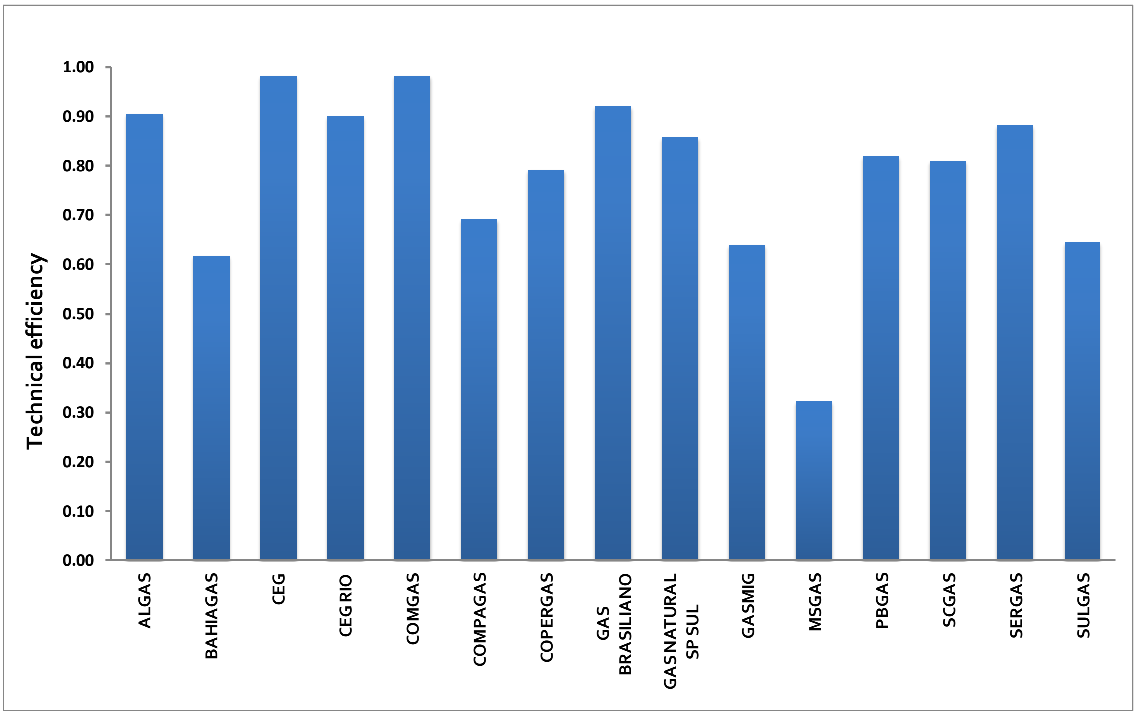
6.2. Firm's efficiency.

Figure 3 shows the firms' average technical efficiency[43] of the Brazilian gas distribution companies, which is estimated to be 78.4%. This average, however, hides very significant differences from firm to firm. Indeed, the performance ranges from 32.3% (Msgas) to 98.2% (Comgas).[44]

43 For the sake of brevity, we only report average results.

44 Except Msgas, the efficiency is above 60% across the sample. The behavior of the production levels of Msgas is very volatile and erratic in this period; meanwhile, the network length has increased in the period. Due to this reason, such firm's results must be taken with caution.

Figure 3 Brazilian gas distribution firms' Average Technical Efficiency. 2001- 2009



Among the companies with the highest level of efficiency, we have found those privately-owned and located in the more developed and large gas markets (more than 90%), such as Comgas, Ceg, and Ceg Rio. It is important to mention that Ceg and Comgas have extensively developed the household and commercial gas markets. They have built an extensive pipeline network, as they are operating since the 19th century. They also have efficiency above 90%, such as Algas y Gas Brasiliano. These companies have both small concession areas and their network concentrated in areas with significant level of industry and population densities. Gas Natural SPS is a newly established distribution private company that is trying to follow the strategy of CEG and Comgas, by investing heavily in the household market. This company has experienced a fast improvement in the efficiency during the period analyzed.

Except Msgas, Bahiagas, Gasmig, and Compagas are the companies with the lowest level of average technical efficiency in the period (see Figure 3). These companies have focused their development strategy on large gas consumers. These results have suggested that a market diversification strategy contributes to increase companies' technical efficiency.

Even though, Figure 3 has provided a good idea of the overall technical efficiency of the industry in the period, a more accurate analysis of efficiency performance requires an analysis of the efficiency evolution by firm. Some of the firm's average efficiency results and, especially, its evolution, are conditioned by the fact that part of the companies was established in 1999,[45] and they have very low efficiency levels at the beginning of the period.

In Table 6 we can observe firms' individual efficiencies per year, which let us scrutinize firms' performance evolution in detail. Gas Natural SPS, Scgas, Compagas, and Sulgas have better performance in terms of technical efficiency increase. Except Gas Natural SPS, these firms are all new established public-owned distribution firms. Such firms have been investing heavily in the creation and expansion of their distribution networks, as we stated before. We can identify others public firms, such as Algas, Bahiagas, Copergas, Gasmig, Pbgas, and Sergas, which have not managed to significantly improve their technical efficiency in the period. They have in common a lower level of inversion during the period, as compared with private or new public companies.

As a consequence of the investment in the network, the private firms' gas sales, such as Comgas, Ceg, Ceg Rio, and Gas Natural SPS, represented by dotted lines in Figure 4, have increased consistently in the period. Public companies, such as Bahiagas, Gasmig, Sulgas, and Msgas, however, have experienced an irregular evolution of gas sales and no significant development.

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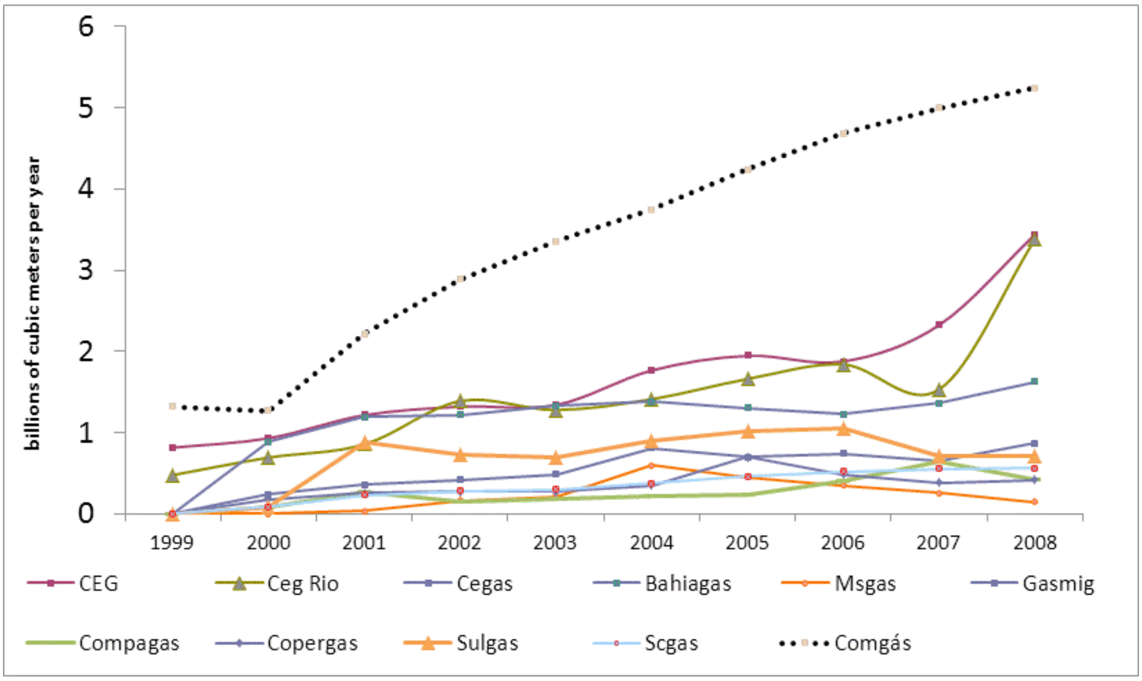
45 Msgas, Gas Brasiliano, Gas Natural SPS, Compagas, Scgas, and Sulgas.

Table 6. Technical Efficiency of the Brazilian gas distribution firms 2001-2009

Firm	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average Technical Efficiency
ALGAS	0.893	0.936	0.977	0.957	0.964	0.943	0.896	0.775	0.796	**0.904**
BAHIAGAS	0.660	0.632	0.541	0.566	0.668	0.634	0.641	0.633	0.581	**0.617**
CEG	0.993	0.985	0.973	0.964	0.983	0.977	0.986	0.988	0.980	**0.981**
CEG RIO	0.787	0.974	0.795	0.881	0.906	0.923	0.989	0.979	0.866	**0.900**
COMGAS	0.976	0.981	0.976	0.983	0.984	0.981	0.984	0.986	0.988	**0.982**
COMPAGAS					0.542	0.601	0.857	0.686	0.775	**0.692**
COPERGAS	0.944	0.978	0.869	0.629	0.797	0.806	0.755	0.662	0.683	**0.791**
GAS BRASILIANO			0.932	0.884	0.924	0.834	0.982	0.960	0.927	**0.920**
GAS NATURAL SP SUL		0.425	0.965	0.894	0.858	0.845	0.933	0.974	0.968	**0.858**
GASMIG	0.705	0.605	0.538	0.679	0.701	0.673	0.679	0.595	0.588	**0.641**
MSGAS					0.326	0.342	0.440	0.193	0.313	**0.323**
PBGAS	0.809	0.851	0.799	0.728	0.970	0.882	0.802	0.758	0.765	**0.818**
SCGAS	0.754	0.735	0.624	0.809	0.802	0.769	0.938	0.889	0.970	**0.810**
SERGAS	0.852	0.963	0.794	0.949	0.958	0.956	0.844	0.739		**0.882**
SULGAS	0.506	0.486	0.525	0.712	0.827	0.661	0.676	0.620	0.793	**0.645**
Average Technical Efficiency	**0.807**	**0.735**	**0.736**	**0.760**	**0.814**	**0.788**	**0.827**	**0.763**	**0.785**	**0.784**

Figure 4. Evolution of gas sales of the main Brazilian distribution firms (1999-2009). (Millions of m^3)



Note: private firms are represented by dotted line.

7. CONCLUSIONS

This paper has estimated a stochastic multi-output distance function for a panel data of 15 natural gas distribution firms in Brazil, from 2001 to 2009, to evaluate the firm's technical efficiency levels and to test whether changes in consumer density and other factors, as load factor, have impacted on the performance of this industry. According to Batesse and Coelli (1995), an explicit model for technical inefficiency has been formulated in terms of appropriate explanatory variables. Moreover, we want to analyze several important issues concerning the energy policy in Brazil, such as the behavior of companies and their regulation by type of ownership, the maturity of the industry, and the network investments level.

We have found a common finding in the literature that is the evidence of considerable density economies, but insignificant or weak scale economies in gas distribution industry. About the efficiency drivers, we have found out important results. From the estimation, we can note that an increase in density of customer and/or load factor have contributed to improve companies' relative efficiency. The efficiency of natural gas distribution companies is affected by the characteristics of the market and its business strategies. Thus, companies developing markets with different demand characteristics, such as large industrial consumers and small domestic consumers, have both increased their efficiency faster and reached higher efficiency levels. We can conclude that the underdeveloped state of the industry, in Brazil, conditions the efficiency levels as found out Ertük and Türut-Asik (2011) for Turkey.

In addition, we have noted that the mode of ownership and different regulation for private companies have a differential effect on the efficiency of firms. As other works (Fabbri et al. 2000), this result suggests a more efficient production in private firms in this industry. The average technical efficiency of the industry ranges from 80.7% to

78.5%, between 2001 and 2009. On a yearly basis, it remained fairly stable. In average, private companies have a significantly higher technical efficiency levels (approximately 90% vs. 75%). In addition, the evolution has been different if we compare by mode of ownership. While public companies have shown a small decline during the period, private companies have a slight favorable evolution, but stabilized in the last three years. Among the companies with the highest level of efficiency, we have found those privately-owned and located in the more developed gas markets. An important point to note is the fact that privately-owned companies and new established public-owned distribution firms have significantly invested more than other public-owned companies, and have managed to greatly improve their technical efficiency in the period.

We can conclude several interesting issues for energy policy. The rate of investment is a necessary condition to allow market diversification, and this strategy contributes to increase companies' technical efficiency. Furthermore, the private ownership and its regulation device are better than the public one. These three findings are important to support the improvement of the gas distribution regulation in the Brazilian states. Thus, State regulation should consider changes in the concession areas, in order to separate areas with high efficiency potential (and financial sustainability) from those where public support will be necessary to promote the gas distribution infrastructure. An appropriate policy would be, through price cap, privatization and regulation of those companies developing markets with different demand characteristics, such as large industrial consumers and small domestic consumers. It is also important to note that a special attention should be paid to the large concession areas with low population density; in this case, the Brazilian states can manage the gas supply firms by employing a cost of service regulation. It is important to set conditions to increase the rate of investments in the states that have not privatized their distribution companies.

As a future research agenda, the confirmation that market diversification is an important drive for increasing technical efficiency will be very important for improving gas regulation policy in Brazil. Most of Brazilian distribution companies have not considered the development of small consumers market in their investment strategy. In this sense, it would be useful to calculate Scope Economies by estimating a Cost Function. Finally, a further work is also required to analyze more deeply other efficiency drivers of Brazilian gas distribution industry and the evolution of its performance. It will be interesting to analyze the differential effects of regulatory reforms in each State and to perform other analyses as the estimation of Total Factor Productivity.

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