The substitution process of heavy fuel oil with natural gas in the industrial sector of Valle del Cauca and Cauca – Colombia 2004-2012

El proceso de sustitución de combustibles pesados por gas natural en el sector industrial del Valle del Cauca y del Cauca - Colombia 2004-2012

Análise e modelagem do processo para a substituição de óleo combustível pesado com a Gas Natural em empresas industriais de Valle del Cauca e Cauca - Colombia 2004-2012

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Abstract

The main purpose of this paper is to analyze the substitution process from heavy fuel oil to natural gas by medium-sized and large companies located in Valle del Cauca and the north of Cauca in the period 2004–2012. Likewise, using a random effects Probit model in Panel, the propensity of these industries to substitute highly polluting fuel with natural gas is estimated. The results show that the difference in cost between natural gas and other fuels is a determinant of the probability of replacement. In addition, it is confirmed that the industries with a lower likelihood of carrying out this replacement are those that use coal in their production processes.

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Keywords: Alternative energy sources, gasification, panel data model.

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Resumen

Este documento tiene por objetivo analizar el proceso de sustitución de la utilización de combustibles pesados hacia el gas natural por parte de medianas y grandes empresas ubicadas en el Valle del Cauca y norte del Cauca, que se observan durante el periodo 2004-2012. Asimismo, utilizando un modelo Probit de efectos aleatorios en Panel, se estima la propensión de estas industrias a sustituir un combustible altamente contaminante por gas natural. Los resultados muestran que la diferencia de gasto en gas con relación a otros combustibles es determinante en la probabilidad de conversión. Adicionalmente, se confirma que las industrias con menos probabilidad de realizar la conversión son aquellas que utilizan carbón en los procesos de producción.

Palabras clave: fuentes de energía alternativa, gasificación, datos de panel.

Resumo

Este trabalho tem por objetivo analisar o processo de substituição do uso de óleo combustível pesado para gás natural por empresas de médio e grande porte localizadas no Valle del Cauca e Cauca, Norte del vistos ao longo do período 2004-2012. Além disso, usando um modelo de efeitos aleatórios Painel de Probit, a propensão destas indústrias é estimada para substituir combustíveis altamente poluentes a gás natural. Os resultados mostram que a diferença de passar sobre o gás em relação a outros combustíveis é crucial para a probabilidade de conversão. Em adição, confirmou-se que as indústrias menos susceptíveis de converter são aqueles que usam processos de produção de carvão.

Palavras-chave: Fontes Alternativas de Energia, gaseificação, dados em painel.

INTRODUCTION

Energy has a crucial role in the industrial and consumption sectors, the use of which produces a series of externalities, associated, almost inevitably, with harmful effects on the environment. It is clear, on the other hand, that most of the fuels used in the industry are of a non-renewable nature, which makes their valuation necessary to guarantee their use for future generations. This leads to the search for an efficient use of energy, which requires a valuation of the performance of the different energy sources within the productive process, in order to achieve an improvement in the equipment that consumes energy resources, through processes of fuel substitution.

According to this idea, the concept of a rational use of energy in Colombia has become stronger in the last few years, as it has become an alternative oriented towards the efficient use of energy, getting rid of its waste and unnecessary use. The rational and efficient use of energy sources not only improves the efficiency and competitiveness of the companies, but also the quality of the environment. Referring to this last point, substitution analysis intends to reduce environmental impact by reducing greenhouse emissions coming from combustion processes, which are highly polluting.

Emission reduction has become one of the political and economic challenges of developed and developing countries, as it is expressed in many treaties and agreements in order to fight against climate change. This began with the signing of the Kyoto Protocol (11 December 1997).

Even when during the 90s, community emissions were reduced by 3.5%, calculations made in the year 2010 indicated that this type of pollution was only reduced by 4.7%, this means, 3.3 per cent below the objective of 8% established in the Kyoto Protocol for the year 2020.

At present, governments seek to incentivize the use of fuels which have a relatively low impact on the emissions sent into the atmosphere. A recent study by the World Health Organization (WHO) estimates that only 12% of the world population who live in cities, breath pure air, and almost half live with pollution 2.5 times greater that the levels recommended by this organization. According to this idea, the use of natural gas represents an improvement as regards the environment, given that in sectors like those of transport and industry, it is mainly used to substitute high emission fossil fuels.

In this scenario, natural gas is proposed as a viable substitute for heavy fuels or coal, or both, which allows for the industrial sector to be competitive and produce the items demanded in a responsible way regarding the environment. Natural gas has become a substitute source of energy to electricity (electric energy) and other fossil fuels in Colombia in the last few years, becoming a solid backup in periods of scarcity, as happened during the Pacific phenomenon (El Niño) in 2009 and part of 2010[1]. The case of the Ballena-Barrancabermeja gasoduct is evidence of this. The volume transported was taken to its maximum load capacity; a situation that was explained mainly due to the high demand of gas thermoelectrics, caused by the effect of El Niño.

The aim of this work is to present different adapted scenarios in the energetic market which show the energetic efficiency of intensive industry in the use of different types of fuels, with respect to CO_2 emissions, calorific and economic performance. The use of the tool is illustrated through the presentation of scenarios of different companies that use diverse energy sources. It is important to highlight that the tool presented do not outline the steps to be followed in making the conversion of the steam boilers that burn liquid fuels to gas. Even

[1]According to the Statistical Review of World Energy (British Petroleum BP, 2013), in the year 2012 natural gas occupied the third position among primary energy sources with 24% of the total worldwide. Some of its main uses are: industrial production, electricity generation or cogeneration.

when it does not intend to be a complete model of analysis of the energy market with balance calculations, it does intend to be a first approximation to it, by formalizing the analysis of fuel substitution regarding an existing gap on the topic.

DYNAMICS OF THE INDUSTRIAL SECTOR IN VALLE DEL CAUCA

The economy of Valle del Cauca differs from the productive structure of the country, which can be noted in that the weight of the production of certain goods and services is superior to the country's average. The high level of concentration in each one of the sectors (as regards agriculture, the activity is concentrated in sugar cane and coftariff, and as regards industry in sugar refineries, oil, and chemical products), made the departmental economy more vulnerable to economic opening, specifically to external clashes. In fact, economic opening contributed to the disappearance of transitory crops and the outsourcing of the department's GDP.

That is to say that, during that period, many companies of Valle had to suspend their production or change their modus operandi, given that they could no longer compete with international prices. Part of the industrial reconversion was related to this process of improving their competitiveness. In this process, the tertiary sector benefited from the situation, as some regional industries opted for commercializing goods and started to require a new economic structure more focused on the distribution of goods and operations of commercial logistics, in order to satisfy the needs that before did not existed in the city nor in the department (Otero, 2012).

In fact, for the year 2010, the Valle's GDP was mainly composed of the activities of the tertiary sector (70%), specifically services, trade, and financial mediation companies. The remaining 30% was produced by activities of the secondary sector (24%) and the primary sector (6%) This composition has been dynamic in time, as in 1990 the tertiary sector contributed 52% to the Valle's GDP, whereas the secondary (industry and construction) contributed 31%. Ten years later, the strength of outsourcing was felt, given that the figures passed to 73% and 20%, respectively.

For the last year of this study, in 2012, the departmental GDP by sectors shows that the financial services sector contributed 26.1%, communal and social services 14.6%, and industry 15.5%. On the other hand, the agricultural sector contributed only 5%, and the electricity, gas, and water sector 3.7% (Otero, 2012). If the analysis is done by exchange rates, it can be observed that during 2007 and 2012 the economic structure was influenced by the clear specialization of the business sector. In effect, if growth rates are analyzed by sector, it will be noted that the one of greatest dynamism was the business sector (4.4%), followed by the mining sector (4.3%), and financial institutions and social services activities (3.8%).

The primary sector is mainly composed of agricultural activities (50% of the sector), among which sugar cane crops (95.17 % of the permanent crops), raw sugar cane –panela- (0.19 %), coftariff (0.35 %), vegetables, cereals (corn, soy, sorghum), and fruit, stand out. In great proportion, the factors that have had an incidence in the stagnation of this sector are associated with the increase of the costs of production, especially those referring to the prices of some agricultural supplies controlled by large monopolies, exorbitant interest rates with the banking sector and high energy costs, such as diesel and electricity, which are above the national average.

It should be noted that the Cauca department, despite of being one of the main areas of the armed conflict, is today an important pillar of economic development, particularly the northern area, where there are about 2,300 large, small, and micro enterprises. This transformation was achieved thanks to the stimuli of tax exemption declared in the north sub-region of the department of Cauca. In the last decade, the economy of Cauca presented an average growth of 6.5% between 2004 and 2013, higher than the country's average (4.8%), and contrary to that of Valle del Cauca, which registered a lower growth than the national average. Finally, even when the department of Cauca is one of the most industrialized of the country, the participation of the industrial sector within the department's GDP is still far from being the most significant.

COMPETITIVE ADVANTAGE: DRIVER OF INDUSTRIAL RECONVERSION

Although it is well-known that economic science has well-developed theories on resource allocation, the question arises of the existence of comparatively clear directions which can be applied to a process of industrial reconversion, in this case referring to the substitution of energy sources.

To the extent that industrial reconversion and restructuring will imply a shift towards a more efficient and competitive economy, does this mean that it should be characterized by what we have understood as activities which have a comparative advantage? Industrial restructuring, as a process seeking the efficient allocation of resources will probably be based on the maximization of profits or the minimization of costs, or both, through the optimization of production techniques.

The objective of industrial reconversion is to make the industrial structure more efficient and more competitive internationally. In this point, the most recommendable would be to put emphasis on the activities where the country has a comparative advantage. However, empirical studies reveal that most of the trade among countries with similar resources is intra-industrial instead of inter-industrial, and the effects of trade income distribution have been lower than expected.

This has led international trade scholars to modify their models, incorporating elements of industrial organization, such as scale economies and other elements of imperfect competition, and even considering a practice punished as severely as dumping, as an important theoretical element within the explanation of international trade. All the elements mentioned above are part of Porter's (2010) competitive advantage theory, which acknowledges that although the abundant endowment of physical resources or cheap labor are still important in the explanation of the competitive advantage of certain basic economic activities, it is also emphasized that these factors are not sufficient to obtain an advantage within international trade. In addition, he claims that the technological change constitutes a means to avoid or overcome the scarcity of the factors, reducing the importance of the endowment of resources of a country in particular. In effect, growth in productivity is essential for competitiveness, which requires industrial restructuring, as is, in this case, the shift towards more competitive energy sources like natural gas. Without doubt, technological improvement is essential for companies' sustainability in the medium and long term.

What is true is that many enterprises do not take advantage of the technical support available in the market, and slowly and skeptically respond to the benefits of new technologies, as in this case the transition to natural gas.

The new paradigm of competitive advantage explains why the enterprises of some countries opt for better strategies than others: the importance of the productivity with which some production factors are employed and the importance of innovations in the methods and technology used.

THE BENEFITS OF THE USE OF NATURAL GAS

Natural gas turns out to be the cheapest fuel in terms of delivered energy (pesos/MMBtu) to boilers, which implies that the cost of steam generation, where fuel has an incidence superior to 80%, is reduced using gas (Chalco, 2005). Natural gas produces a better combustion thanks to the fact that it is in a molecular state and its components react in a more complete way with oxygen molecules. A more efficient combustion takes place because it requires less air in the burner which, at the same time, produces less CO_2 and zero particles. The above occurs because natural gas heaters do not require steam, as opposed to liquid fuels that do need it, and this not only avoids the cost of steam or the electricity demand to compress the air, but it is also advantageous to fulfill the norms on the maximum limits permitted of emissions of greenhouse gas and particles in suspension that may become stricter in a not too distant future.

Another advantage is the fact that as it does not have highly corrosive sulphur components (it is a clean combustion), it is less aggressive to the boilers, which is translated into less stops and maintenance costs due to corroded ducts or cleaning.

The good use of energy is carried out efficiently, given that by producing less soot deposits and less unburned matter as a product of combustion, the losses of energy through the chimney are less and more thermal efficiency in the boiler is achieved (Chalco, 2005). Finally, as it does not require storage, when the gas is delivered in a reliable way through pipes, it is handled in a relatively safer and more reliable manner so as to avoid spills in tank, lines and heaters.

Advantages of using natural gas in the different industrial sectors

In general, natural gas is the best fuel to be used in industries that use ovens and boilers in their productive processes, given its calorific characteristics; it satisfactorily replaces the other fuels. For example, in the glass industry, in which flames that allow for the transmission of caloric energy to the crystal mass are required, natural gas meets this requisite in addition to producing a cleaner product in relation to other fuels.

Regarding the food sector, natural gas allows for efficient cooking and drying processes, also facilitating the fulfillment of the best manufacturing practices (BMP) program and even ISO norms for exporting.

In the textile industry, the use of natural gas permits energy saving in an interval of 20% to 30% by using heat transfer processes by convection in contraposition to the traditional ones that use intermediate fluids. The same happens in the glass industry, the products of this type of industry require some degree of cleanliness, which is achieved with the use of natural gas. The cement industry uses, in their processes, ovens that extend their useful life with gas, as continuous maintenance is not required. Moreover, it is sufficient to see the surroundings of the production plants to realize that cement plants that use coal in their boilers cause great pollution and, in this sense, the use of natural gas in this sector has great benefits for the environment (Kozulk, 2004).

In the processes of melting metals, natural gas has characteristics that allows it to be used in the different processes of heating metals, not only in the fusion, but also in the reheating, without previous preparation for its use, such as heating it or pulverizing it in the case of coal, which makes it more efficient, cleaner, and cheaper in applications like steam boilers, dryers, ovens, and heaters.

In all the industries mentioned, natural gas also offers a number of advantages. The first one is cogeneration, which is the joint production of usable electric and calorific energy. This cogeneration allows for the covering of the energy needs of the production plant as well as that of all the premises. Another advantage is that, as it does not require storage tanks, the risks inherent in storage are reduced. Moreover, once the demand of heat ceases in the processes gas combustion can finish immediately afterwards, which favors the processes that require variable or intermittent charges. All these advantages will allow the companies that make the conversion to natural gas to reduce their operational costs and, thus, be more competitive (Longwell, 2002).

To conclude, a point that must not be forgotten is that, although natural gas constitutes a safe and clean source of energy, certain safety norms have to be taken into consideration regarding the manipulation and the maintenance of the equipment. At the same time, the use of leak detection automatic systems is required.

Emissions analysis

The combustion of any fossil fuel releases heat that is used, in a great part, in the generation of steam in boilers. The main products of combustion are CO_2 (carbon dioxide), H_2O (water), CO (carbon monoxide), NO_x (nitrogen oxide), and SO_2 (sulphur dioxide). Of the above mentioned gases, CO_2 is considered a greenhouse gas while the rest are considered air pollutants. It should be noted that the emission factor is generally expressed as the weight of the pollutant emitted by the unit of weight, volume, energy, or activity, depending on the level chosen. In general, the emission of gases and particles derived from the combustion processes of fossil sources, as well as the difficulty of combustion, increase when passing from using gases to using diesel and from diesel to residual oils.

The referential method worldwide to estimate the CO_2 emissions associated to energy activities is the one proposed by the IPCC (Intergovernmental Panel on Climate Change), which consists of counting the volume of carbon contained in the fossil fuels that the country uses (Lee, 2004). Assuming that CO_2 emissions depend basically on the characteristics of fuels and not on the technologies of their use, as is the case of the other pollutants, below a comparative chart of the different fuels and factors of emission is presented[2].

Table 1. Carbon and CO_2 emission factors by type of fuel[3].

Fuel	**State**	**Emission factor (KG C/GJ)**
Coal	Solid	26,8
Crude oil		20,2
Diesel		22,2
Fuel oil	Liquid	21,1
Gasoline		18,9
Kerosene		19,5
Propane gas – LPG	Gas	17,2
Natural gas		15,3

Source: IPCC (1996).

It can be observed that natural gas is the fuel with the lowest emission factor of CO_2 as well as in the emission of chimney emissions, such as CO, NO_x, and SO_2.

The carbon content of a liquid or solid fossil fuel varies according to their physical and chemical properties. With regard to natural gas, its emission factor depends on the gas composition, which apart from methane can include small quantities of ethane, propane, butane, and heavy hydrocarbons. According to this, emissions depend on the proportion or participation of each one. Below, the percentage of CO_2 in emissions by type of fuel is analyzed.

[2] Emissions are all the gaseous fluids, pure, or with substances in suspension; as well as all forms of radioactive, electromagnetic, or sound energy that result from waste or products of human or natural activity (for example: plants which emit CO_2).
[3] Emission factor calculated from the stequimetric equation.

Table 2. Percentage of emissions by fuel[4].

Mbtu energy unit	**Fuel**	**Produces CO2**
14,89 Mbtu	Natural gas	1
	LPG	1,02
	Crude	1,08
	Diesel (ACPM)	1,16
	Fuel oil	1,21
	Gasoline	1,23
	Mineral coal	1,72
	Electric energy	2,08
	Bagasse	3,7

Source: Gases de Occidente S.A. E.S.P.

The calculation of CO_2 emissions stemming from the ignition of fossil fuels is directly related to two parameters: the amount of fuel consumed and the carbon content of each one of them, bagasse, electrical energy and carbon being the ones with the highest emission.

The estimations presented in Table 2 are founded on the theoretical bases provided by the stoichiometry of each one of the fuels, established from their elemental composition[5]. The chemical equations that govern combustion reactions are:

$$CnHM + \left(n + (m/4)\right)0_2 \rightarrow (m/2)H_20 \qquad [1]$$

Being aware of the elemental composition of the fuel and the corresponding stoichiometric equations, it is possible to calculate the number of products obtained on a certain basis of fuel. As it is a purely theoretical analysis, a complete combustion in stoichiometry conditions is assumed, in which case the products are only CO_2 and H_20.

Taking the data of the industrial sector by municipalities of Valle del Cauca for the year 2013, the participation of the emissions that are no longer generated thanks to the use of natural gas can be observed. Even when at first sight it would seem that the differences are not significant, actually the differences of emissions, when large quantities of pollutant fuels are considered, become obvious (See Table 3).

[4] BTU is a British energy unit (millions of British Thermal Units). A BTU represents the amount of energy required to elevate the temperature of a pound of water in normal atmospheric conditions in one Fahrenheit degree. A cubic tarifft of natural gas emits on average 1,000 BTU, although the value interval is between 500 and 1,500 BTU.

[5] Stoichiometry is the science that measures the quantitative proportions or mass relations of the chemical elements which are involved in a chemical reaction.

Table 3. Summary of emissions by fuel and by municipality

Municipio	No Industria	ACPCM	Carbon	EE	Fuel Oil	GLP	Total Ciudad	Gas Natural	Dif
Cali	122	2289342	N.A	2094774	469134	217544	5070794	3500114	1570680
Andalucia	1	N.A	N.A	N.A	3522	N.A	3522	2911	611
Buenaventura	4	1.805	N.A	N.A	N.A	437	2242	1920	322
Buga	20	190331	N.A	N.A	3.533	954746	1148610	1096243	52367
Bugalagrande	2	290832	N.A	N.A	N.A	13180	304012	253279	50733
Caicedonia	1	N.A	N.A	N.A	448	N.A	448	370	78
Candelaria	18	2166	N.A	N.A	60644	12317	75127	63984	11143
Caloto	6	136707	N.A		N.A	120291	256998	230417	26581
Cartago	6	N.A	N.A	2157477	372642	8310	2538429	1343364	1195065
El Cerrito	1	N.A	N.A	N.A	15244	N.A	15244	12598	2646
Guachene	2	N.A	N.A	N.A	N.A	14793	14793	14503	290
Ginebra	1	N.A	N.A	N.A	N.A	19139	19139	18763	376
Guacari	2	N.A	N.A	N.A	1269	2542	3811	3540	271
Jamundi	6	25708	N.A	832237	21622	3797	883364	457419	425945
La Union	1	9941	N.A	N.A	N.A	N.A	9941	8216	1725
Palmira	39	1582646	N.A	1039800	85835	205696	2913977	2080477	833500
Puerto Tejada	2	31118	N.A	N.A	N.A	24	31142	25741	5401
Roldanillo	2	N.A	N.A	N.A	944	N.A	944	780	164
San Pedro	2	N.A	N.A	N.A	N.A	4798	4798	4704	94
Sevilla	2	N.A	N.A	N.A	N.A	4068	4068	3989	79
Tulua	9	24562	N.A	N.A	144930	20108	189600	159789	29811
Villarica	4	14940	N.A	N.A	50760	19453	85153	73370	11783
Yumbo	82	930799	8832789	4999614	1654197	1225091	17642490	10876433	6766057
Santander	1	22354	N.A	N.A	N.A	N.A	22354	18475	3879
Zarzal	3	N.A	356924	N.A	N.A	18891	375815	225839	149976
Total	338	5552651	9189712	11153992	2884723	2865025	31646103	20477238	11168865

*N.A. Information unavailable

Source: Gases de Occidente S.A. E.S.P.

As it can be observed, the differences in emissions by 2013 in favor of the use of natural gas in Valle del Cauca are obvious. There is a saving in emissions for the total of the department of 35.1%. Within the total of emissions for the department, the high participation of electric energy and coal stand out (coal is the most polluting).

Calorific analysis of the different fuels against natural gas

One of the most important variables when making the decision of substituting a fuel is its calorific power, the main element for combustion. Below the calorific characteristics of solid, liquid and gas fuels are presented, in relation to the measurement unit used in the Colombian market. It is worth noting that the calorific power is the energy released in the complete combustion of a mass, matter or volume unit of a fuel in a stoichiometric mix with air[6].

Table 4. Calorific power of the different fuels

Fuel	Measurement unit	Calorific power
Diesel (ACPM)	Btu/Gl	1
Bagasse	Btu/Ton	1,02
Mineral coal	Btu/Ton	1,08
Natural gas	Btu/Gl	1,16
Crude	Btu/kWh	1,21
Electric energy	Btu/Gl	1,23
Fuel oil	Btu/m3	1,72
LPG	Btu/Gl	2,08
Gasoline	Btu/Gl	3,7

Source: Gases de Occidente S.A. E.S.P.

The first step for the conversion is to calculate the quantity of cubic meters (m^3) that have to be used in the replacement of current fuel with the following equation[7].

$$m^3ng = \frac{CP\ CF}{M.unit} \times \frac{1ft^3}{1000\ Btu} \times \frac{1m^3}{35.31467ft^3} = Quantity\ of\ natural\ gas\ (m^3) \quad [2]$$

The equation calculates the amount of m^3 of natural gas that substitutes the other fuel. Taking as an example the conversion of diesel to natural gas, the equation calculates the quantity of the necessary $m^{3\ of}$ natural gas to cover the calorific requirements:

$$\underbrace{138000\ Btu}_{1\ gallon\ of\ Diesel} \times \underbrace{1ft^3}_{1000\ BTU} \times \underbrace{1m^3}_{35.31467} = 3.91m^3 [3]$$

[6] The calorific power is considered inferior when the water formed in combustion is in steam state with the other products of combustion. It is considered superior when the water formed in is liquid phase (condensed).
[7]CP CF = calorific power current fuel; M. unit = Measurement unit used; ft^3= cubic feet.

In this example, in order to replace one (1) gallon of diesel, with a calorific power of *138.000 Btu / gl*, 3.91 m^3 of natural gas with a calorific power of *1000 Btu/ft3* are required. The equation above allows for the elaboration of the following table so as to speed up the calculations of the necessary cubic meters to make the fuel substitution.

Table 5. Conversion of the different types of energy sources to natural gas

Fuel	**Measurement Unit**	**Multiplying factor**	**Obtains**
Diesel	Gallon	3.900.772	
Bagasse	Kilogram	0.21804	
Mineral coal	Pound	0.622971	
Crude	Gallon	4.190.892	m^3 of natural gas
Electric energy	kWh	0.096617	
Fuel oil	Gallon	4.247.527	
LPG	Gallon	2.605.150	
Gasoline	Gallon	3.267.764	

Source: Gases de Occidente S.A. E.S.P.

MODELING THE SUBSTITUTION PROCESS OF THE FIRM

Data

The source of the data is the natural gas provider for the southwest region, Gases de Occidente S.A. E.S.P., which has a panel data structure. There is data for the period 2009-2012 for 338 firms located in Valle del Cauca and the north of Cauca. The dependent variable is a binary one that indicates if the firm has done the conversion to natural gas called *Status* (=1 if it converts to natural gas, =0 if it does not). The total of the sample can be broken into regulated and non-regulated companies, the first ones being small companies, and the second ones being large companies.

The companies of the sample correspond to 25 municipalities, mostly from Valle del Cauca and on a smaller scale from Cauca's northern sub-region. The municipalities in the sample are: Cali, Andalucía, Buenaventura, Buga, Bugalagrande, Caicedonia, Candelaria, Caloto, Cartago, El Cerrito, Guachene, Ginebra, Guacari, Jamundí, La Unión, Palmira, Puerto Tejada, Roldanillo, San Pedro, Sevilla, Tuluá, Villarrica, Yumbo, Santander de Quilichao, and Zarzal. The database consists of companies (regulated and non-regulated) that at some point *t* during the period of time of the study have made the transition from diesel, coal, electric energy, fuel oil, and LPG to natural gas. It is worth noting that even though there are companies from the industrial sector in the database, there is no information of their

ISIC code or if they have changed sectors. The database does not have this information due to the privacy policy of the company Gases de Occidente.

The information is available for 338 companies throughout the period between 2009-2012, constituting a balanced panel, which consists of the companies that converted to natural gas and those that did not. The database has previously been used by Gases de Occidente, so there is no room for missing information. Given the commitment of the company to the confidentiality of the data, there is only information on a consecutive (number assigned to company X) and not on a commercial name.

Modeling the probability that a company makes the transition to natural gas, the explanatory variables chosen were the type of fuel used before the conversion in the $t-1$ period; including 5 fuel alternatives: diesel, LPG, coal, fuel oil, and electric energy. Five dichotomous variables were built in order to model these five fuel alternatives, taking the value 1 if they belong to fuel I and 0 for the other fuels j. The inclusion of these variables will reveal the probability of converting to natural gas, given the fuel used in the moment $t-1$.

Considered as a consensus, the decisions of businessmen are based on production costs. This includes the *Diftari* variable, defined in thousands of Colombian pesos, which is the difference in the alternative fuels tariffs against the tariff of natural gas. Finally, the *emissions* variable (of CO_2 measured in tons) is included to quantify the effect of this variable over the probability of making the conversion.

Saving, defined as the difference between tariffs, could be considered conservative, for no other savings are considered for the heating of residuals, additives, shrinkage, pumping or system maintenance, when alternative fuels to natural gas are used. However, as there is no information regarding these variables, the difference between tariffs is included with the objective of identifying probabilities of substitution depending on the fuel that was used before the transition to natural gas.

Binary linear selection models

This section considers the models in which the response variable y_{it} in the panel structure takes values 1 and 0, a binary dependent variable. Modeling the decision that a company converts to natural gas is modeling the decision of a rational agent that maximizes a function of benefits subject to restrictions that lead them to decide to convert or not. Constructing latent variables as a selection strategy and having in mind that the choice has to be done according to the characteristics of the agent, the following scheme is presented:

$$y_{it}^{*} = x_{it}\beta + c_i + u_{it}$$

$$y_{it} = 1[y_{it}^{*} > 0]$$

$$y_{it} = 0[y_{it}^{*} \leq 0]$$

y_{it}^* being the propensity to conversion the company is (which cannot be observed), these models allow for relating latent variables (non-observable variables) based on observable characteristics of the companies; x_{it} is the vector of explanatory variables.

The transition towards Probit and Logit models is justified due to the problems that linear probability models face, as is the case of heteroskedasticity and unbounded probabilities between 0 and 1.

Binary non-linear selection models: Probit and Logit

The treatment of the company's decision is approached using Logit and Probit models which allow working with non-linear specifications. Using the following latent variable scheme:

$$y_{it}^* = x_{it}\beta + c_i + u_{it}$$

$$y_{it} = 1[y_{it}^* > 0]$$

$$Pr(y_{it} = 1|x_{it}, c_i) = G(x_{it}\beta + c_i)$$

If the term of non-observable heterogeneity c_i can be related to the explanatory variables, it causes the estimators not to have the desired properties.

The Logit model of fixed effects appears as an alternative solution, as it allows for the elimination of the term c_i from the equation once there is a condition of what is referred to as "minimum sufficient statistic" for c_i (Wooldridge, 2005).

While the traditional Logit model of random effects requires strict exogeneity, the Logit model of fixed effects relaxes the assumption of strict exogeneity. However, this model cannot obtain consistent estimations of c_i and, for this reason, the conventional marginal effects cannot be calculated. This constitutes a great inconvenience, given the need to obtain the marginal effects, for being non-linear models, the initial estimators obtained lack any kind of interpretation. Accordingly, the Logit panel model with fixed effects is discarded (Hsiao, 1986).

As an alternative of estimation, the traditional Probit model with random effects is used. This methodology establishes a series of assumptions of the error term with the non-observable error term, among others:

- c_i y x_{it} are independent,
- x_{it} is strictly exogenous (which is necessary to specify the verisimilitude function when a series of exits is observed and deals with them as the individual product of verisimilitude factors),

- c_i has a normal distribution with average 0 and variance,
- $y_{it} \ldots y_{iT}$ are conditional independents over (x_{it}, c_i).

It can be observed that the assumptions are restrictive, especially because the endogeneity in the explanatory variables is discarded. The only advantage of the Probit model with random effects over the pooled Probit model is that it allows for the correlation of non-observable factors $(c_i + u_{it})$.

Although in linear models it is easy to eliminate the c_i component, whether it is using the first differences or with the "within" transformation, those options are not available for a non-linear model such as Probit, in which differentiation is not possible. This is why there is no option to directly estimate with a Probit model with fixed effects (Harris & Rogers, 2003).

On the other hand, if c_i is estimated directly adding $N - 1$ dichotomous variables for each observation (company), this would generate a bias in the estimators, except that T is big, which does not occur in this case. This is known as the incidental parameter problem: with a small T, the estimation of c_i is inconsistent, given that an increase in N does not remove the bias (the same happens in the Logit model). For this reason, the estimation of the term c_i Probit model via dichotomous variables is discarded in favor of the Probit model of random effects, as it was initially established.

The specification of the Probit model with random effects is as follows:

$$\mathrm{status}_{i,t} = \beta_1 \mathrm{Diftari}_{i,t} + \beta_2 \mathrm{Emissions}_{i,t} + \beta_3 \mathrm{Coal}_{i,t} + \beta_4 \mathrm{Fuel}_{i,t} + \beta_4 \mathrm{Lpg}_{i,t} + \beta_4 \mathrm{diesel}_{i,t} + v_{i,t}$$
$$\text{With } v_{i,t} = (c_i + u_{i,t})$$

It is important to highlight that the EE variable (electric energy) is not included in the model to be estimated, given that in preliminary tests it is excluded due to perfect multicollinearity problems.

Regarding the expected signs, a positive sign for the β_1 estimator is predicted, given that upon increasing the difference of alternative fuel tariffs against natural gas, the probability of making the conversion increases, too. This explicitly reflects the rational behavior of the businessman by minimizing production costs, given the greater cost of fuel oil, LPG, and diesel against the tariff on natural gas, positive signs in the estimators associated to these dichotomous variables are expected. With regard to the dichotomous variable coal, it is predicted that it could have a negative sign, as it is the only fuel of the available ones with a lower price compared to natural gas. Finally, a positive sign is expected for the estimator associated with the emissions variable, for environmental regulations punish highly pollutant processes. In this case, the higher the pollutant load of the type of fuel used, the greater the incentive to make the industrial conversion to natural gas.

The results of the marginal effects of the Probit model with random effects in panel data are summarized below:

Table 6. Marginal effects of the Probit model with random effects

Variable	**Estimator**	**Stat. deviation** [8]	**Significance**
Diftari	0.04348	0.0046	0.000
Emissions	0.00009	$7.47e^{-6}$	0.000
Coal	-1.23169	0.083	0.013
Fuel	0.97337	0.2605	0.000
LPG	1.25571	0.2506	0.000
Diesel	0.59290	0.2444	0.015

Source: calculations made by the author, based on STATA12.0 estimations

The option to calculate the marginal effects in STATA in a panel is slightly different for a Probit model with crossed section or transversal data. The option pu0 calculates the probability assuming that the random effect for an observation in the panel equals 0.

It is observed that all the variables are significant, individually as well as in group (see the exit of Probit model of the Wald statistical level of significance). The results are the expected ones as regards the signs of the estimators. Starting with the differences in the fossil fuel with respect to the natural gas variable (Diftari), its estimator indicates that for a 1000 Colombian peso increase in the tariff, the probability of doing a transition to natural gas increases in 4.3%. Although this estimator is probably biased by the existence of a non-observable heterogeneity term, c_i, the model is presented with the objective of estimating differentials in the probability of the transition to natural gas by fuel type. At the same time, it is found that the greater the value of emissions, more likely the company is to make the transition to natural gas. A tendency that was noted in the last few years is that consumers have incorporated the concept of responsible consumption, that is, they acquire products that minimize the impact on the environment.

Analyzing the magnitude of the estimators that accompany the dichotomous variables, there is one that stands out due to the relative size of the marginal effect (1.25571) of a company that uses LPG, being the type of company likely to change to natural gas. It is followed in probability by a company that at the moment uses $T-1$ *fuel* as main fuel with a 0.97 coefficient.

The above contrasts with the companies that used to use coal as their main source of energy; they have lower probabilities of converting. In effect, if the company uses coal before the conversion, its probability of undergoing a transition is even negative. The explanation resides in the low cost of coal (even cheaper than gas) among all the other

[8] Calculated with the delta method.

energy alternatives. The production cost factor is the most relevant at the moment of making the decision of converting to natural gas.

TO SUBSTITUTE OR NOT TO SUBSTITUTE, THAT IS THE QUESTION

The industries that use among their processes boilers that burn residual oils and have access to natural gas can opt to change to a new boiler that has a gas burner incorporated or, otherwise, they can change or adapt the existing burner so it can burn natural gas. Though initially the choice will depend on the state of the boiler or its capacity limit, among other factors, also, the cost saving is one of the determinants for said conversion (Dahl & Matson, 1998).

The high participation of fossil fuels with high emission loads has its answer in two factors: the first one is their low cost, taking into consideration the technology that the industrial sector of the country uses, which is not modern; secondly, how permissive the state entities of control are. Despite the fact that 23% can be considered a low percentage, it should be noted that it can be closer to the "roof" as long as the industry acknowledges the loss of competitiveness of the alternative fuels to natural gas. What prevents the use of gas in the industrial sector? The first restriction is the lack of knowledge as regards the applicability of natural gas in diverse productive activities in industries that use boilers, ovens, pots, and other industrial equipment. Additionally, there is a myth that large investments have to be made in order to carry out the substitution, without a previous analysis of the current fuel against natural gas, which allows for a comparison of the calorific quality of the different alternatives (Axelsson, Harvey & Berntsson, 2009).

According to this, the decision of companies to move from different fuels to natural gas will depend on the competitiveness of this fuel with respect to the price and energy power factors. If gas is not competitive regarding these variables, the companies that use coal and LPG surely will not carry out the transition to natural gas. It is not very likely that businessmen will put the competitiveness of the industry at risk by doing the conversion to gas if it is not competitive with regard to the variables mentioned. Other variables for the businessman to take into consideration, apart from the cost of the fuel, are the initial costs of the investment, the cost of maintenance, and the evaluation of personal exposure (Rodríguez, 2006).

Before superficially reviewing the necessary process for the conversion of steam boilers to natural gas, it is required to acquire and install a natural gas provision system that consists of pipes (a connection of the supplier with the users), valve trains, a meter, filters, relief valves, supports, and pressure reducers; all of which should be done under strict security rules. It is worth noting that the old systems of fuel provision need not necessarily be annulled, for they can be conserved as back-up in case of an unexpected natural gas shortage.

According to Chalco (2005), an effective conversion to natural gas requires the development of the following sequence:

1. Revision of heat transfer.
2. Evaluation of the ability of the materials.
3. Study of the structural dilatations regarding the new temperature demands.
4. Revision and adaptation of the boiler equipment, such as the burner, fan, economizer, and controls.
5. Additional analysis: revision of polluting emissions, capacity of production of the steam boiler, technical efficiency and back-up fuels.
6. Maintenance costs.

Substitution analysis

The cost of converting to natural gas depends on a series of variables such as the type and capacity of the boiler; brand and type of burner, valve trains, and other types of accessories that vary depending on the capacity of the boiler. In addition, it is necessary to install a pressure reduction station and a gas consumption meter at the entrance of the plant. Finally, the length of the pipe has to be taken into consideration, which allows for a connection between the provider and the final user, as well as the distribution pipes within the plant.

Given that each investment depends on the type of boiler and as this information was not provided by the primary data source (Gases de Occidente), it is not possible to know the cost of the investment of natural gas in each of the companies that underwent the transition.

In spite of this, there is information as regards the total investment of some companies that use different fuels, which without being representative of the sector that uses LPG, fuel oil, or other sources, does allow an approximation as to the time required to recover the initial investment, based on the difference between the price of other fuels against natural gas.

It is worth mentioning that the substitution analysis must take into account the maintenance costs related to the equipment that in the moment $t-1$ used diesel, coal, LPG, or fuel oil. Said costs can be broken down into internal and external labor, parts, and maintenance costs specific to each piece of equipment. Although the savings in the use of natural gas are, in part, due to its lower tariff, it also has to be taken into consideration that the maintenance costs are reduced, as the maintenance and cleaning of mechanical components is lower in absolute terms.

From the point of view of production, the use of natural gas also shows several operational advantages, such as the reduction of improductive time in the plant, given to flaws in the ignition equipment, in the combustion equipment, which causes the suspension of certain productive processes. Secondly, time for cleaning and maintenance of the combustion equipment resulting in halts in the production can be reduced. In this way, with the use of gas as a main fuel, the frequency of stops decreases, nevertheless, this source of energy also requires preventive maintenance, as well as the revision of the system of burners.

Different scenarios of the energy market have been proposed by a large number of authors in the literature, in general, linked to studies of future energy systems using energy models.

However, it is usually very difficult to obtain a number of coherent data sets for the energy market that can be used to evaluate new investments in systems of industrial energy (Axelsson, Harvey & Berntsson, 2009). It is postulated that most of the benefits are based on the difference between the current prices of the alternative fuels and natural gas. It is clear that this difference can change, in a dynamic context, as is the oil market, which could change the demands of gas in the industrial sector.

The following exercise does not intend to be an adequate tool to generate such scenarios, however, regarding the existing gap on the topic, it is approached as a first approximation.

Below, three substitution examples are analyzed for the three fossil fuels with a high emission load[9]. Three companies from the sample are used, which have different energy requirements for their functioning, the conversion factors presented in the previous section to calculate the number of gallons of natural gas to make the substitution. The prices and costs correspond to the year 2013, and the analysis is made with respect to diesel, LPG, and coal.

The first subtitution exercise is carried out with a company from the sample which uses diesel to generate steam with a boiler. The conversion analysis allows for the calculation of the requirements or demands on natural gas to obtain the same energy for each one of the fuels (Painuly & Parikh,1993).

Table 7. Cost comparison: alternative fuels versus natural gas[10]

Fuel	M. unit	Col $ / M. unit	Unit/month	Cost value/month
Diesel	Gallon	$ 8,115.00	12000	97.380.000
Natural gas	m3	896	46893	42.015.848
Conversion factor: 3.907724				
LPG	Gallon	$ 4,200.00	15000	63.000.000
Natural gas	m3	896	39077	35.013.211
Conversion factor: 2.605150				
Coal	Kg	$ 210,00	300	87.000.000
Natural gas	m3	510	186891	95.314.497

Source: Gases de Occidente S.A. E.S.P.

The exercise shows that by substituting diesel with natural gas, the monthly saving is 43% of the cost, which is equivalent to COL$ 55,364,151, while the investments that have to be made in this type of industry are approximately COL$130,000,000, which can be recovered in approximately 2.4 months.

[9] The examples presented in this section were carried out with companies of the sample given by the company Gases de Occidente. Due to privacy policies, the names of the different companies are omitted.
[10] The measurement unit corresponds to the average price for 2013, associated cost: $80.

Following with a company that uses LPG to generate steam with a boiler, the exercise shows that when substituting LPG with natural gas, there is a 44% saving, equivalent to COL$27,986,788. The investment for this type of industry is of approximately COL$95,000,000, and its recovery time is estimated as 3.4 months.

Finally, the energy source with the highest percentage of CO_2 emissions of the three is analyzed. The example will be given with a company that uses coal to generate steam with a boiler.

Taking into account that for this type of company, due to the high amount of natural gas required, the *Comisión de Regulación de Gas y Energía* (CREG)[11] classifies the user as a non-regulated industrial client. The result of the exercise shows that when substituting coal with natural gas, there is no saving, given that the cost overrun is around 10%, which is equivalent to an initial cost of COL$8,314,496, making the situation even less viable.

In this scenario a question arises: how to achieve that these companies are willing to make the transition to natural gas when the main variable, the costs, do not favor the situation? The answer lies in the alliances that the providers or distributors of natural gas make with Ecopetrol (producer) and the TGI (transporter) to guarantee an appealing tariff for the client. And thus, allow for substitution. Making agreements between the agents of the natural gas chain with the aim of reducing the final tariffs is a key factor in the massification of gas as an alternative for industries.

It should be noted that in the valuation of the different fuels, the costs associated with the use are omitted. They elevate the cost of the energy related to the following activities:

- Electricity consumption due to recirculation
- Cost of maintenance stops.
- Waste and final disposal of residuals.
- Inefficiency for unburned matter.
- Environmental permits or licenses.

In the case of diesel the energy cost increases by a minimum of $90 per gallon, while the costs associated with the use of LPG go up to a minimum of $40 per gallon. An additional cost related to the consumption of evaporators (excluding permits or environmental licenses and electricicity consumption by recirculation) must be added in the case of LPG.

In the valuation of coal, the costs associated with its use must be included, which elevate the energy cost by a minimum of $80 per kilo in relation to the activities previously listed. Finally, the conversion of the equipment to natural gas produces a quantified environmental

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[11] CREG (by its acronym in Spanish, Commission of Energy and Gas Regulation) is an organism which depends on the Ministry for Mines and Energy, in charge of promulgating the necessary norms to regulate the sectors of energy and gas in Colombia.

benefit of CO_2, CO, NOx and particled material, which will allow the fulfillment of the environmental regulations of the Colombian state.

CONCLUSIONS

For the industrial sector of Valle del Cauca and the north of Cauca there are potential advantages for the users of steam boilers by having access to a fuel such as natural gas, not only due to its efficiency and its relatively low price, but also due to the low environmental pollution that it produces. Each company, at the moment of making the decision, should weigh several factors, such as the current type and level of consumption of the fuel, the capacity of the boiler and how old it is, and possible thermal risks when making the conversion to natural gas.

The decision of the companies to make the transition from the other fuels to natural gas will depend on the competitiveness of this fuel with respect to the variablesof price and energetic power. It is quite likely that if gas is not competitive regarding these variables, the companies that use coal and LPG will not make the transition to natural gas, as it is not very likely that businessmen will put the competitiveness of the industry at risk.

Although the difference in costs between the fuel used and gas constitute the main variable when taking the idea of the transition seriously, the initial investment cost, the maintenance costs, and the evaluation of risk of exposure of the personnel are also important.

The Probit model with random effects for data panels allows for the identification of the fact that cost saving is a significant variable when thinking about the viability of a fuel substitution project. It is confirmed that the fuels that are least probable to be substituted are coal, LPG, and biomass, due to the low cost of use that they have. In these specific cases, efforts between the agents of the chain have to be made so as to look for a more competitive and long term price, which allows for the necessary investments to be made, given that with these substitutions large figures could be obtained in the reduction of tons of $CO_{2.}$

Also, it is confirmed that the emissions variable is significant, which is a result that was expected. In fact, it is presumed that the corporate image with a clean and responsible production with the environment is translated into profits for the company in the medium and long term, given that consumers prefer to buy products that are environmentally-friendly.

Finally, while the cost factor is essential when making the decision of reconversion, it is also true that there are risks with respect to the rise in the price of natural gas due to the increase in the price of oil. Additionally, it has to be taken into consideration that the current bottle necks regarding infrastructure are yet to be solved with the aim of making the transport of gas to its final users cheaper.

REFERENCES

Axelsson, E., Harvey, S. & Berntsson, T. (2009). A tool for creating energy market scenarios for evaluation of investments in energy intensive industry.*Energy*, *34*(12), 2069-2074.

Cameron, C. & Trivedi, P. (2010). *Microeconometrics using Stata*. USA: The Stata Press.

Chalco, V. (2005). *Beneficios de la conversión a gas natural en calderas de vapor*. Recuperado de http://www.unmsm.edu.pe/cedit/linked/analisis%20de%20cambio%20de%20combustible.pdf

Dahl, C. A. & Matson, T. K. (1998). Evolution of the US natural gas industry in response to changes in transaction costs. *Land Economics*, 390-408.

Harris, M. & Rogers, M. (2003). Modelling firm innovations using panel probit estimators. *Melbourne Institute Working Paper, 20*(1).

Hsiao, C. (1986). *Analysis of panel data*. Cambridge: Cambridge University Press.

IPCC (1996). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories: Reference Manual IPCC*. U.K.: Bracknell.

Kozulk, R. (2004). *La industria del gas natural en América del Sur: situación y posibilidades de integración de los mercados*. Chile: Cepal.

Lee, W. (2004). US lessons for energy industry restructuring: based on natural gas and California electricity incidences. *Energy Policy, 32*(2), 237-259.

Longwell, H. J. (2002). The future of the oil and gas industry: past approaches, new challenges. *World Energy*, *5*(3), 100-104.

Otero, A. (2012). Cali a comienzos del siglo XXI. ¿Crisis o recuperación? *Documentos de trabajo sobre economía regional Banco de la Republica*, (172). Recuperado de http://mba.americaeconomia.com/sites/mba.americaeconomia.com/files/dtser_172.pdf

Porter, M. (2010). *Ventaja competitiva. Creación y sostenibilidad de un rendimiento superior*. Madrid: Pirámide.

Painuly, J. P. & Parikh, J. (1993). Policy analysis of oil substitution by natural gas in India: Transport and industry sectors. *Energy policy*, *21*(1), 43-52.

Rodríguez, M. (2006). *Estimación de la demanda de combustibles en República Dominicana.* Texto 6. República Dominicana: Unidad de Análisis Económico Secretariado Técnico de la Presidencia.

Wooldridge, J. (2005). *Econometric analysis of cross section and panel data*. Cambridge, MA: The MIT Press.

Appendix 1.

Heteroskedasticity Test

```
. regress  status diftari  v18 acpm fuel glp carbon ee, nocons
```

Source	SS	df	MS
Model	927.337686	7	132.476812
Residual	727.662314	3023	.240708672
Total	1655	3030	.54620462

Number of obs	=	3030
F(7, 3023)	=	550.36
Prob > F	=	0.0000
R-squared	=	0.5603
Adj R-squared	=	0.5593
Root MSE	=	.49062

status	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
diftari	.0155066	.0060782	2.55	0.011	.0035887	.0274244
v18	2.89e-07	3.84e-08	7.53	0.000	2.14e-07	3.64e-07
acpm	.4244574	.0379694	11.18	0.000	.3500089	.4989059
fuel	.4452339	.0247154	18.01	0.000	.3967731	.4936947
glp	.5284457	.0235171	22.47	0.000	.4823346	.5745568
carbon	.3377584	.0830746	4.07	0.000	.17487	.5006468
ee	.4109048	.0822044	5.00	0.000	.2497226	.572087

Appendix 2.

Probabilities between 0 and 1.

```
White's test for Ho: homoskedasticity
         against Ha: unrestricted heteroskedasticity

         chi2(17)      =    1073.03
         Prob > chi2   =     0.0000
```

Appendix 3.

```
sum yhat
```

Variable	Obs	Mean	Std. Dev.	Min	Max
yhat	3030	.5462046	.0878356	.3328777	2.336972

Appendix 4.

```
Random-effects probit regression                Number of obs      =      3032
Group variable: suscriptor                      Number of groups   =       338

Random effects u_i ~ Gaussian                   Obs per group: min =         8
                                                               avg =       9.0
                                                               max =         9

                                                Wald chi2(6)       =    269.20
Log likelihood  = -830.36272                    Prob > chi2        =    0.0000
```

status	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
diftari	.4035746	.0424594	9.50	0.000	.3203557	.4867935
emisiones	.0008791	.0000689	12.75	0.000	.0007439	.0010142
acpm	5.502601	2.299023	2.39	0.017	.9965995	10.0086
fuel	9.033605	2.367844	3.82	0.000	4.392716	13.67449
glp	11.83955	2.277426	5.20	0.000	7.375873	16.30322
carbon	-11.43101	4.546603	-2.51	0.012	-20.34219	-2.519836
_cons	-13.6874	2.304528	-5.94	0.000	-18.20419	-9.170604
/lnsig2u	4.56862	.1818478			4.212205	4.925035
sigma_u	9.818907	.8927732			8.216154	11.73431
rho	.9897342	.0018476			.9854026	.9927899

```
Likelihood-ratio test of rho=0: chibar2(01) =  1177.02 Prob >= chibar2 = 0.000
```

Appendix 5.

```
Average marginal effects                          Number of obs    =      3032
Model VCE    : OIM

Expression   : Pr(status=1 assuming u_i=0), predict(pu0)
dy/dx w.r.t. : emisiones diftari acpm fuel glp carbon
```

	dy/dx	Delta-method Std. Err.	z	P>|z|	[95% Conf.	Interval]
emisiones	.0000947	7.47e-06	12.68	0.000	.0000801	.0001094
diftari	.0434852	.0046553	9.34	0.000	.0343611	.0526094
acpm	.5929062	.244413	2.43	0.015	.1138656	1.071947
fuel	.9733726	.2605962	3.74	0.000	.4626134	1.484132
glp	1.275713	.2506863	5.09	0.000	.784377	1.767049
carbon	-1.231695	.4940745	-2.49	0.013	-2.200063	-.2633263