Universidad de Concepción
Dirección de Postgrado
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Programa Magister en Economía en Recursos Naturales y del Medio Ambiente

Analysis and Decomposition of Energy Consumption in the Chilean Industry

Análisis y Descomposición del Consumo de Energía en la Industria Chilena

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CONCEPCIÓN – CHILE
2014

Tesis para optar al grado de Magister en Economía de Recursos Naturales y del Medio Ambiente

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Abstract

In a scenario of rising energy costs, global warming and climate change, energy efficiency might play a central role to reduce the impact on the environment of industrial activities, while keeping the competitiveness of the industry. This thesis aims at analyzing what explain the changes in the efficiency of energy consumption in Chile's industry. In order to provide policy-makers with the information needed to determine whether energy efficiency policies can play a role in the industrial sector in Chile and if it is better to have a unique or a differentiated energy efficiency policy for Chile's industry. The logarithmic mean Divisia index method I is used for the decomposition analysis.

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Chapter 1

Introduction

In times of energy crisis, rising energy costs, and climate change, energy efficiency is one of the cheapest, cleanest and a secure way to deal with these problems. Energy efficiency implies keeping the same levels of benefits while using less energy. At the industry level, energy efficient technologies use less energy than conventional technologies by keeping the same quantity and quality of production, and often have lower costs and pollute less [Reddy and Ray, 2011].

In Chile, oil, gas and coal represent 78 percent of the total primary energy consumption and the country imports about 80 percent of these fossil fuels [IEA, 2009]. This external dependence makes Chile's economy highly vulnerable to external shocks at the energy markets. Moreover, Chile's industry and mining activities account for more than 65 percent of the overall electricity consumption and in terms of aggregate energy consumption -considering electricity, fossil fuels and firewood- they use more than 35 percent of the total [CNE, 2007].

Currently, energy demand is growing quickly in Chile, energy prices are still rising and future energy supply is uncertain, thus making energy policy and energy efficiency an increasingly important issue for Chile's economy.

How to measure energy efficiency has been an important research topic during the last four decades. It is a fact that higher energy consumption does not always imply less energy efficiency. It has been recognized that changes in energy consumption are widely influenced by the scale of economic activities (the activity effect), the economic structure in terms of energy intensiveness (the structure effect) and changes in energy intensity -defined as energy used per unit of output- (the intensity effect). This last effect is considered a good proxy of changes in energy efficiency and was explained by changes in the sectorial technological level [Sun, 1998].

An important method used to evaluate energy efficiency is the decomposition analysis. This approach provides a good picture of what happens with energy consumption. Different studies have found that energy consumption changes for different reasons, and energy efficiency is only one of them. See, for example, [Rue du Can et al., 2012], [Reddy and Ray, 2011], and [Balezentis et al., 2011].This information is important for policymakers because it allows them to design appropriate strategies for reduction in energy consumption because different effects imply different strategies.

The objective of this thesis is to understand the mechanisms of change of energy consumption in Chile's industry and determine whether or not there exist differences in energy efficiency changes among firms of different activity sector, size and kind of property. This could provide policymakers with the information needed to determine if energy efficiency policies can play a role in reductions of energy consumption of the industrial sector in Chile. In addition, it aims at investigating whether it is better to have a unique or a differentiated energy efficiency policy for Chile's industry.

Chapter 2

Chilean Energy Background

2.1 Energy in Chile

In Chile there is a growing concern about energy. In fact, for the first time in its history, in 2013 a presidential debate took place specifically to discuss an energy issue. Currently, there are doubts about the ability to meet future energy demand, and energy in Chile is unstable, expensive and dirty.

As seen in Figure 2.1 , energy consumption has grown fast. The final energy consumption between 1991 and 2011 increased by 122 percent. The main reason for this grow is the continued expansion of the Gross Domestic Product (GDP). Until now, there is a coupling between GDP growth and energy consumption. One objective of the Energy Ministry is to achieve a decoupling between these two variables. Energy efficiency is crucial to accomplish this decoupling and to reduce future energy demand [of Energy, 2013].

Oil, gas and coal represent 78 percent of the total primary energy consumption and the country imports close to 80 percent of these fossil fuels [IEA, 2009]. This external dependence makes Chile highly vulnerable when facing external shocks. This became clear when in 2004 the gas crisis took place with Argentina; in this occasion, the neighboring country interrupted the natural gas exports to meet domestic demand, leaving Chile in a critical situation.

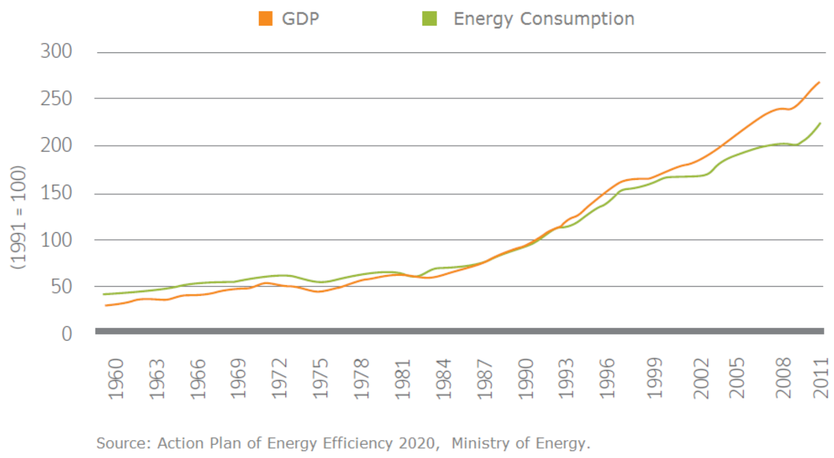

Figure 2.1: Evolution of Energy Consumption and GDP in Chile

The Chilean electric system is divided into four sectors based on geography:

- The Northern Interconnected System (SING) where large firms, mainly mining companies, account for about 90 percent of electricity consumption;
- The Central Interconnected System (SIC) that provides electricity to more than 90 percent of the country's population;
- The southern Aysen electric system;
- and, the Magallanes electric system, [IEA, 2009].

The activity of the electrical system is divided in: generation, transmission and distribution. All these activities are controlled by private firms. Three companies –Endesa Chile, Colbun and AES Gener– control almost 90 percent of electricity generation. Currently, the price of electricity for households since 1998 has nearly quadrupled. And, energy prices in Chile exceed the average of OCDE countries by 60 percent, [IEA, 2012].

In the last few years the energy matrix was increasing in carbonization. Investment in new coal-powered plants is expanding at a much faster rate than is on renewable energy sources. In absolute terms, the energy sector contributes in a dominant and growing way to the national emission of

CO2, with an increase of 124.6 percent between 1990 and 2010, which in 2010 reached a value of 69.7 million tonnes of CO2 equivalent [IEA, 2012]. That is, somewhat faster than the increase in energy demand during the same period.

2.2 Industry in Chile

In Chile, mining was responsible for 14.2 percent and manufacturing industry for the 11.2 percent of the PIB in 2012. As observed in Figure 2.2, the main sectors of manufacturing industry are: food, beverage and tabacco (36 percent); refined petroleum, chemical, rubber and plastic(20.3 percent); metalic products , machinery and equipment(19.2 percent); woodpulp, paper and printing materials(10.1 percent);nonmetallic minerals and basic metal(8 percent);wood and furniture(4.2) percent; and, textile, clothing, leather and foot wear (2.2 percent). Copper is the most important export item, for it self represent more that 50 percent of the total exports. Destination markets for Chilean exports remains highly diversified. Asia is the principal export destination for mining and Europe for the rest of the industrial exports, [SOFOFA, 2012].

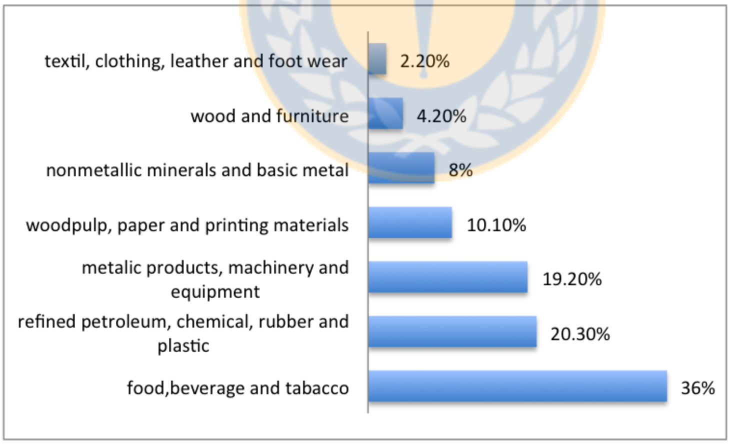

Figure 2.2: Structure of GDP in the Industry 2012

Chile's industry is the greatest consumer of electricity within the country. Industry and mining companies accounts for more than 65 percent of the overall electricity consumption. Also, in terms of total energy, considering fossil fuels and firewood, the industry and mining companies utilize more than 35 percent of the total and the energy demand of those sectors is growing quickly, [CNE, 2007]. This is the reason why understanding the industrial demand for energy is crucial to define future energy efficiency policies.

2.3 Energy Policy

The current Chilean government goal towards energy efficiency points at obtaining a 12 percent reduction in projected energy consumption by 2020. To achieve this goal, the Ministry of Energy published the Action Plan of Energy Efficiency 2020. This plan establishes that 39 percent of the expected reduction will occur in the industrial and mining sector.

In this respect, the measures to achieve the development in the industrial and mining sector are:

- promote the implementation of energy management systems
- promote and encourage cogeneration
- promotion of technical assistance projects
- incorporation of efficient technologies

Internationally, IEA analysis shows that substantial opportunities to improve industrial energy efficiency worldwide exist. Overall potential energy savings in the industrial sector in 2010 are equivalent to the current annual electricity consumption of the United States and China combined, [IEA, 2011].

To achieve energy savings in the industrial sector, the IEA recommends that governments:

- Support industry adoption of energy management protocols.
- Mandate minimum energy performance standards (MEPS) for electric motors.
- Implement a package of measures to promote energy efficiency in small and medium-sized enterprises (SMEs).
- Put in place complementary financial policies that promote energy-efficient investment.

Chapter 3

Methodology

This chapter begins with a brief explanation of the Index Number Theory based on *Producer Price Index Manual* [IMF, 2004]. Then, introduces the bases of the decomposition method, and explains why we chosen the Logarithmic Mean Divisia Index Method I (LMDII) for our study. After that, presents some empirical studies. And finally, submits, step by step, the empirical methodology.

3.1 Index Number Theory

Index number theory aims at resolving how to aggregate the microeconomic information involving possibly millions of prices and quantities into a smaller number. In words of the *Manual* *"the purpose of an index number is to decompose proportionate or percentage changes in values aggregates into their overall price an quantity change components*", [IMF, 2004].

A *price index* is a measure or function that summarize the change in the prices of a set of products from one situation 0 to another situation 1. An *aggregated* V for a given collection of items and transactions is computed as

$$V = \sum_{i=1}^{n} p_i q_i, \tag{3.1}$$

where p_i represents the price of the ith item in national currency units, q_i represents the corresponding quantity transacted in the time period under consideration, and the subscript i identifies the ith elementary item in the group of n items that make up the chosen value aggregate V.

Considering the aggregated value for two time periods, the *base period*, 0, and the *current period*, 1. The value aggregate in the two periods are defined as

$$V^0 = \sum_{i=1}^{n} p_i q_i, \tag{3.2}$$

$$V^1 = \sum_{i=1}^{n} p_i q_i. \tag{3.3}$$

Now we define a *price index*, $P(p^0, p^1, q^0, q^1)$, and the corresponding *quantity index*, $Q(p^0, p^1, q^0, q^1)$, as functions of $4n$ variables. These two functions satisfy the following equation:

$$\frac{V^1}{V^0} = P(p^0, p^1, q^0, q^1) \times Q(p^0, p^1, q^0, q^1). \tag{3.4}$$

This equation means that if we know the value ratio and either P or Q is determined, then the other function is implicitly determined. Different authors propose many indexes to solve this problem. In this section we will present the one we are going to use, the Divisia index.

3.1.1 The Divisia Index

The Divisia Index was proposed and analyzed formally by François Divisia in 1926. Originally, it was designed in order to incorporate quantity and price changes over time from subcomponents which are measured in different units. The Divisia Index considers that if prices and quantities are continuous functions of time, the aggregate value is defined as follows,

$$V(t) \equiv \sum_{i=1}^{n} p_i(t) q_i(t). \tag{3.5}$$

Both functions , $p_i(t)$ and $q_i(t)$, are assumed to be differentiable. Then,

$$V'(t) = \sum_{i=1}^{n} p_i'(t) q_i(t) + \sum_{i=1}^{n} p_i(t) q_i'(t). \tag{3.6}$$

Then, dividing both sides by $V(t)$,

$$\frac{V'(t)}{V(t)} = \frac{\sum_{i=1}^{n} p_i'(t)q_i(t) + \sum_{i=1}^{n} p_i(t)q_i'(t)}{\sum_{i=1}^{n} p_i(t)q_i(t)} = \sum_{i=1}^{n} \frac{p_i'(t)}{p_i(t)} s_i(t) + \sum_{i=1}^{n} \frac{q_i'(t)}{q_i(t)} s_i(t), \tag{3.7}$$

where $s_i(t)$ is the share at time t of the expenditures on product i over total expenditures at the same period. Formally,

$$s_i(t) \equiv \frac{p_i(t)q_i(t)}{\sum_{m=1}^{n} p_m(t)q_m(t)}. \tag{3.8}$$

The French economist, François Divisia, proposes that if aggregate value at time t, $V(t)$, can be written as the product of a time t price-level function, $P(t)$, and time t quantity-level function, $Q(t)$. That is,

$$V(t) = P(t)Q(t). \tag{3.9}$$

Suppose that both functions, $P(t)$ and $Q(t)$, are differentiable. Then,

$$V'(t) = P'(t)Q(t) + P(t)Q'(t). \tag{3.10}$$

Then dividing both sides trough $V(t)$,

$$\frac{V'(t)}{V(t)} = \frac{P'(t)}{P(t)} + \frac{Q'(t)}{Q(t)}. \tag{3.11}$$

Divisia compared the two expressions for the logarithmic value derivative, $V'(t)/V(t)$, and he simply define the rate of change of the aggregate price level, $P'(t)/P(t)$, as

$$\frac{P'(t)}{P(t)} = \sum_{i=1}^{n} \frac{p_i'(t)}{p_i(t)} s_i(t). \tag{3.12}$$

And the rate of change of the aggregate quantity level,$Q'(t)/Q(t)$, as

$$\frac{Q'(t)}{Q(t)} = \sum_{i=1}^{n} \frac{q_i'(t)}{q_i(t)} s_i(t). \tag{3.13}$$

3.2 Decomposition Method

How to measure energy efficiency has been an important research topic during the last four decades. The Decomposition Analysis based on the Index Number Theory was widely used to break down changes in energy consumption and explain them in terms of changes in:

- the scale of economic activities (**the activity effect**). This component refers to the level of output. In most studies about industry this effect was measured considering the value added. [Liu and Ang, 2007]
- the importance or participation of the different sectors within the economy (**the structure effect**). This component represents the mix of activities or the structure of industries in terms of energy intensiveness. It is measured considering the participation of each sector or product in the economy.
- and, the energy intensity, defined as energy used per unit of output (**the intensity effect**). This component shows changes in energy intensity and it is considered a good proxy of changes in energy efficiency. It was explained by changes in the sectorial technological level. [Sun, 1998]

Different methods have been proposed to break down the changes in aggregate energy consumption. These methods are based on index number theory and could be divided into two groups: the methods linked to the Laspeyres index [Sun, 1998] and methods linked to the Divisia index [Ang, 2005]. Each method has an additive version and a multiplicative version.

Figure 3.1 shows the method as evaluated by [Ang, 2004]. His study presents the strengths and weaknesses of each method and concludes that the logarithmic mean Divisia index method I (LMDI) to be the preferred one.

This conclusion was based on:

- theoretical foundations: This method satisfies the factor-reversal test, this mean it gives perfect decomposition whereby no unexplained residual term appears in the results. As well, this method satisfies the time reversal test, this mean that the results do not depend on the base year. Also, this method is consistent in aggregation, [Ang and Liu, 2001].

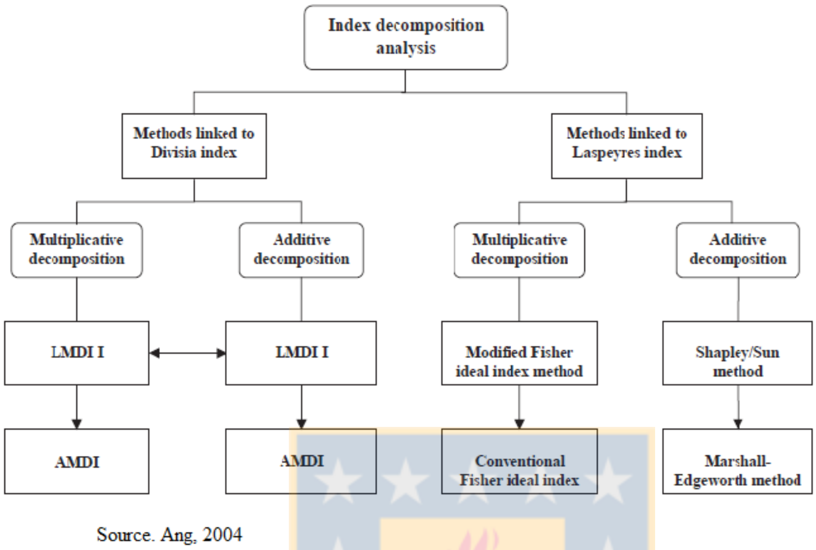

Figure 3.1: Recommended Methods for Energy Decomposition Analysis

- adaptability: This method is capable of handling data sets with zero values, or negative values,
- the ease of use and results interpretation: because, as discussed in the next section, the decomposition formula takes a rather simple form. Also, the linkages between the multiplicative version and the additive version can be established easily.

Because of all these characteristics, the LMDII method has gained popularity among researchers. Consequently, we are going to use this approach in our study.

Depending of the data used there are physical energy intensity and economic energy intensity indicators. On one hand, physical indicators measure energy used per physical unit of output produced by some sector. Those indicators provide more reliable estimations since they are less affected by trends in economy and price-related reasons [Reddy and Ray, 2011]. However, using them presents the problem of aggregating across indicators expressed in different units at the aggregate level. Nanduri and his associated [Nanduri et al., 2002] review diverse aggregation methods. Nevertheless, those methods required a large data base. On the other hand, economic energy intensity indicators measure the energy used per dollar of GDP produced by some sector. Those indicators are preferred at national or sector aggregated levels.

In this study, we use the logarithmic mean Divisia index method I for the decomposition analysis and we work with economic energy intensity indicators because of characteristics of the data available.

3.2.1 The Logarithmic Mean Divisia Index I (LMDII) formulation

The Logarithmic Mean Divisia Index Method I (LMDI I) was presented by Ang and Liu, [Ang and Liu, 2001]. This method allows to decomposing an aggregate indicator and find the measures of the relative contributions of a set of pre-defined factors.

The notation and formulation was taken from [Ang, 2005]. Let V^t an aggregate explained by n factors, then

$$V^t = \sum_i x^t_{1,i} x^t_{2,i} \dots x^t_{n,i}, \tag{3.14}$$

where subscript i denotes a sub-category of the aggregate and t is the time period.

Considering two periods of time: $t = 0$ for the base period and $t = T$ for the current period. We decompose the aggregate change from $V^0 = \sum_i x^0_{1,i} x^0_{2,i} \dots x^0_{n,i}$ to $V^T = \sum_i x^T_{1,i} x^T_{2,i} \dots x^T_{n,i}$.

For a multiplicative decomposition we decompose the ratio:

$$D = \frac{V^T}{V^0} = D_{x_1} D_{x_2} \dots D_{x_n}. \tag{3.15}$$

Following [Ang and Liu, 2001] the effect of the kth factor is given by

$$D_{x_k} = \exp(\sum_i \frac{L(V^T_i, V^0_i)}{L(V^T, V^0)}) \ln \left(\frac{x^T_{k,i}}{x^0_{k,i}} \right). \tag{3.16}$$

For an additive decomposition we decompose the difference:

$$\Delta V = V^T - V^0 = \Delta V_{x_1} + \Delta V_{x_2} + \ldots + \Delta V_{x_n}. \tag{3.17}$$

Following [Ang et al., 1998] the effect of the kth factor is given by

$$\Delta V_{x_k} = \sum_i L(V_i^T, V_i^0) \ln \left(\frac{x_{k,i}^T}{x_{k,i}^0} \right), \tag{3.18}$$

where the function $L(V_i^T, V_i^0)$ is the logarithmic average given by

$$L(V_i^T, V_i^0) = \frac{V_i^T - V_i^0}{\ln V_i^T - \ln V_i^0} \quad for \quad V_i^T \neq V_i^0. \tag{3.19}$$

3.3 Empirical Methodology

In order to find the changes in energy efficiency, we need to find the impact of the intensity effect. With this aim, first, we must calculate the total energy consumption and then compute and decompose the change of energy consumption.

After finding the total energy consumption, we obtain the change in industrial energy consumption, defined as,

$$\Delta E = E^t - E^{t-1}, \tag{3.20}$$

where E^t and E^{t-1} are the energy consumed during period t and $t-1$, respectively.

The following index decomposition analysis (IDA) identity describes the total energy consumption. Let subscript i be a sub-category of the aggregate energy consumption in industrial sector i.

$$E = \sum_i E_i = \sum_i Q \frac{Q_i}{Q} \frac{E_i}{Q_i} = \sum_i Q S_i I_i, \tag{3.21}$$

where E is the total energy consumption in the industry, $Q = \sum_i Q_i$ is the total industrial activity level, and $S_i = \sum_i Q_i/Q$ and $I_i = \sum_i E_i/Q_i$ are, respectively, the activity share and energy intensity of sector i.

For an additive decomposition, we decompose the difference:

$$\Delta E = E^t - E^{t-1} = \Delta E_{act} + \Delta E_{str} + \Delta E_{int}, \tag{3.22}$$

where,

$$\Delta E_{act} = \sum_i \frac{E_i^t - E_i^{t-1}}{\ln E_i^t - \ln E_i^{t-1}} \ln\left(\frac{Q^t}{Q^{t-1}}\right), \tag{3.23}$$

$$\Delta E_{str} = \sum_i \frac{E_i^t - E_i^{t-1}}{\ln E_i^t - \ln E_i^{t-1}} \ln\left(\frac{S_i^t}{S_i^{t-1}}\right), \tag{3.24}$$

$$\Delta E_{int} = \sum_i \frac{E_i^t - E_i^{t-1}}{\ln E_i^t - \ln E_i^{t-1}} \ln\left(\frac{I_i^t}{I_i^{t-1}}\right). \tag{3.25}$$

The subscripts *act*, *str* and *int* denote the effects associated with the overall activity level, activity structure and sectoral energy intensity, respectively.

We will use one important property; LMDI is consistent with aggregation [Ang and Liu, 2001]. Estimates of an effect at the sub-group level can be aggregated to give the corresponding effect at the group level. Thus, we estimate these effects by firm, which, then, can be aggregated by different characteristics.

Finally, we can generate an unbalanced panel data at the firm level and estimate which features are significant to explain the changes in energy intensity. With this information, in one hand, we can analyze what explain the changes of energy consumption in Chile's industry and resolve whether energy efficiency policies can play a role. On the other hand, look at the difference between firms can be useful for policymakers to determine if it is better a unique or a differentiated energy efficiency policy for Chile's industry.

3.4 Previous Empirical Studies

For a better understanding about how the decomposition analysis could help to design energy efficiency policies, it is important to know previous empirical studies and their contribution to the energy analysis in their respective countries.

The use of index decomposition analysis to understand the mechanisms of change in industry of energy consumption began in the late 1970s, after the world oil crisis. Currently, this is a well established and widely used technique. Five main application areas may be identified: energy demand and supply; energy-related gas emissions; material flow and dematerialization; national energy efficiency trend monitoring; and, cross-country comparisons, [Ang, 2004].

[Rue du Can et al., 2012] decomposed energy consumption of California's industry in the period 1997-2008. The results show that even when the production grows in the period, total energy consumption decreases. This reduction is explained by two effects. First, for a change in industry structure, at the beginning of the period the oil and gas extraction was the most important sector and in the last years the electronic industry has grown in importance. This means a transition from a more intensive industry to a lower one. And second, the important decrease in energy intensity. This was attributed to an increase on energy prices and to policies with an aggressive energy-efficiency target.

[Reddy and Ray, 2011] examines energy consumption in different Indian manufacturing sectors. Decomposition analysis discloses an improvement in energy efficiency in the period 1991-2005, shown by a negative intensity effect. Most of the sectors, including cement, textiles, pulp and paper industries, reduced its energy consumption. This reduction is explained, in some cases, by efficiency improvements and , in other cases, by a shift to more efficient energy sources. Also, for some sectors, like aluminium, the energy consumption grows in the period despite improvements in efficiency, this was explained by movements towards more energy-intensive products.

[Balezentis et al., 2011] analyzed energy efficiency trends in Lithuania's economy in the period 1995-2009. They evaluated the impact of some energy efficiency policies and the impact of the economic downturn period. On one hand, they found a positive impact of energy efficiency policies in the period before the downturn, shown by a positive intensity effect. On the other hand, they found that energy efficiency falls during economic downturn period. This result was supported by a negative activity effect, because industry produced less during the downturn. Also, they observed an important positive structural effect in the period, this last effect shows the important changes in Lithuanian's activity-mix.

[Liu and Ang, 2007] analyzed a large number of studies that use the decomposition method to explain changes on energy consumption in different countries. They found that decreases in energy consumption of the industrial countries over the past three decades were explained mainly for the intensity effect.

All these studies provide a complete picture of what happens in terms of energy consumption in their respective countries, and this is essential when policy makers want to set energy efficiency policies.

Chapter 4

Data

The data used in this thesis has been taken from the Encuesta Nacional Industrial Anual (ENIA) for the period 1998-2009. This annual survey provides information about firms with 10 or more workers, who were occupied by at least one semester. It covers more than 5000 firms each year.

These data allow us to follow the firms over time, in form of unbalanced panel data. This provides information about energy consumption, production and other characteristics at firm level, such as: activity sector, size and kind of property.

To measure the energy consumption we use information about different energy sources on physical units used by firms, those are:

- Electricity
- Firewood
- Coal
- Oil and Disel
- Paraffine
- Gasoline
- Natural gas
- Liquified gas

These sources were aggregated as teracalories using the corresponding transformation coefficients published yearly by the Ministry of Energy in the National Energy Balance.

The output was measured using the value added for each firm, expressed in millions of pesos. To classify the firms by activity sector, the ENIA use the International Standard Industrial Classification of All Economic Activities Rev. 3 (ISIC3). This classifier is approved and published by the Statistical Commission of the United Nations. The firms are classified by size considering the number of workers. And, with respect to the kind of property, the firms could be:

- national private
- foreign private
- mixed
- state-owned

4.1 Data Analysis

A preliminary analysis of these data revealed a number of consistency problems, especially when recording the energy consumption of the firms. In some cases, erroneous measurement units were recorded; in other cases, none at all.

Table 4.1 shows the measurement units used each year. For some years we have two possible measurement units, and the most serious problem arises because during the period 2000-2004 the measurement units were not specified. This could mean, in the case of coal, that we should add tons and kilos, and multiply the coal consumption by a thousand for some firms.

Figure 4.1 shows the participation of the different energy sources in energy consumption. We could observe substantial changes in the participation of certain sources in different years. To a large extent these changes could be explained by problems with the measurement units. The participation of some energy sources, such as gasoline and kerosene, in the period 1998-2004, semme to be especially inconsistent. For these reasons we decided to work only with the period 2005-2009.

	1998	1999	2000	2001	2002	2003
Electricity	kwh	kwh		kwh	kwh	kwh
Firewood	t	t		t - mr	t - mr	t - mr
Coal	t	t		t - Kg	t - Kg	t - Kg
Oil and Disel	th. l	th. l		t - m3	t - m4	t - m5
Paraffine	th. l	th. l		m3 - l	m3 - l	m3 - l
Gasoline	th. l	th. l		m3 - l	m3 - l	m3 - l
Natural Gas	m3	m3		m3	m3	m3
Liquified Gas	kg	kg		Kg - m3	Kg - m3	Kg - m3
	2004	**2005**	**2006**	**2007**	**2008**	**2009**
Electricity	kwh	kwh	kwh	kwh	kwh	kwh
Firewood	t - mr	t o mr	t o mr	t o mr	t	t
Coal	t - Kg	t - Kg	t - Kg	t - Kg	Kg	Kg
Oil and Disel	t - m3	t - m3	t - m3	t - m3	m3	m3
Paraffine	m3 - l	m3 - l	m3 - l	m3 - l	l	l
Gasoline	m3 - l	m3 - l	m3 - l	m3 - l	l	l
Natural Gas	m3	m3	m3	m3	m3	m3
Liquified Gas	Kg - m3	Kg - m3	Kg - m3	Kg - m3	Kg	Kg

Table 4.1: Measurement Units

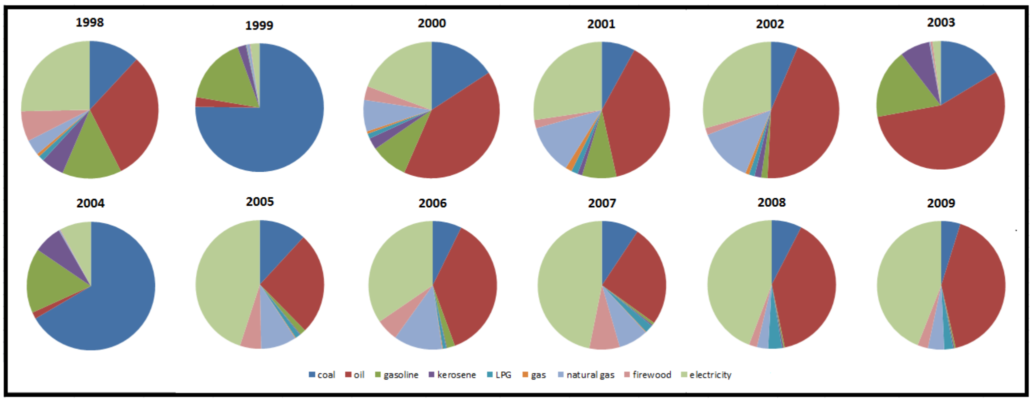

Figure 4.1: Energy Consumption by Sources

Chapter 5

Results

5.1 Decomposition Analysis

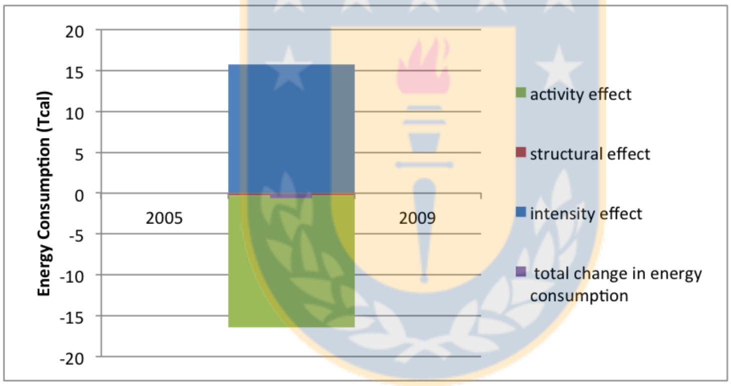

Figure 5.1: Decomposition of Total Energy Consumption

Figure 5.1 shows the results of a decomposition analysis of the changes in energy consumption of Chile's industries. The purple column represents the total change in energy consumption, the green column represents the activity effect, the red column represents the structural effect, and the blue column represents the intensity effect.

As we can see in the graph, energy consumption keeps stable during the period. However, this result hides two opposite effects. First, a negative activity effect. This effect shows an important reduction on energy consumption explained by a reduction on the level of output in the period under study. This reduction could be associated the subprime crisis. Second, a positive intensity effect, that shows an increase in energy consumption explained by a loss of energy efficiency during the period considered.

During the last few years, it has been discussed in Chile the possibility of a decoupling between growth of the economy and growth of energy consumption, since 2005. However, our results show that in the industrial sector even when energy consumption keeps stable, there is an important loss in energy effciency counteracted by a lower production. Thus, we can expect that energy consumption will grow again when the economy is reactivated. This result is important for policy makers because the decoupling will not be permanent if energy efficiency does not improve.

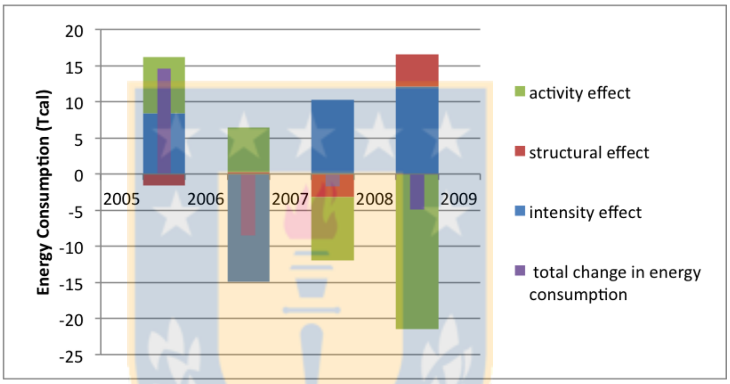

Figure 5.2: Decomposition of Total Energy Consumption by Year. 2005-2009

Figure 5.2 shows the decomposition of the yearly changes in energy consumption of the Chilean industry. We can see a reduction on energy consumption since the year 2006. This reduction was explain by a lower energy intensity in the period 2006-2007, and by a lower production in the following years. The changes in the industry structure does not have a relevant impact on energy consumption during the period.

Two facts are remarkable. First, the results show an important variability of energy intensity in time. And, second, we see an increase of energy intensity in periods of economic crisis . Those results are in line with other studies. For example, [Balezentis et al., 2011] and [Liu and Ang, 2007], where the results suggets an important variability of energy efficiency in time and an increase of energy intensity during economic downturns in different economies.

5.1.1 Decomposition Analysis by Sector

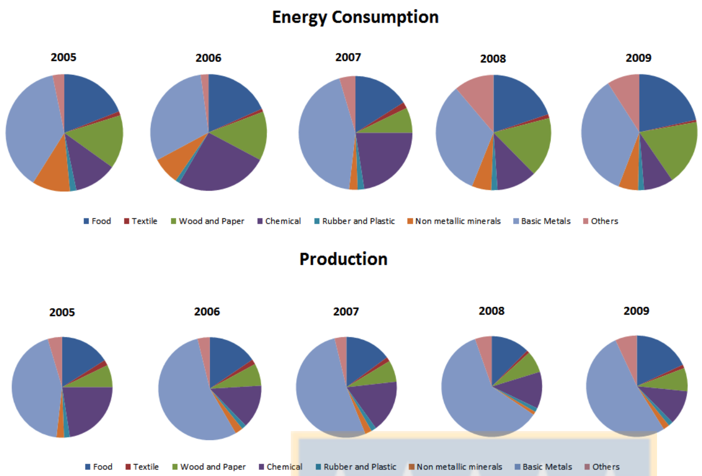

Figure 5.3: Production and Energy Consumption by Sector

Figure 5.3 shows the share of each sector in total production (added value) and the share of each sector in total energy consumption. The main sector in terms of both production and energy consumption is Basic Metals where the subsector Industry Primary Product of Precious and Non-Ferrous Metal explains almost all its share.

In this study, we analyze four sectors because of their importance in terms of production and energy consumption. These are:

- Manufacture of Basic Metals
- Elaboration of Alimentary Products and Drinks
- Manufacture of Substances and Chemical Products
- Timber Production, Manufacture of Paper and Other Products

Figure 5.4 shows the energy intensity of the main industrial sectors. We can see that the wood and paper industry has a higher intensity than the other sectors, the food sector has a medium intensity, and the chemical and the basic metal sectors have an intensity below the others. The energy intensity of the chemical sector grew during 2006. This unexpected growth can

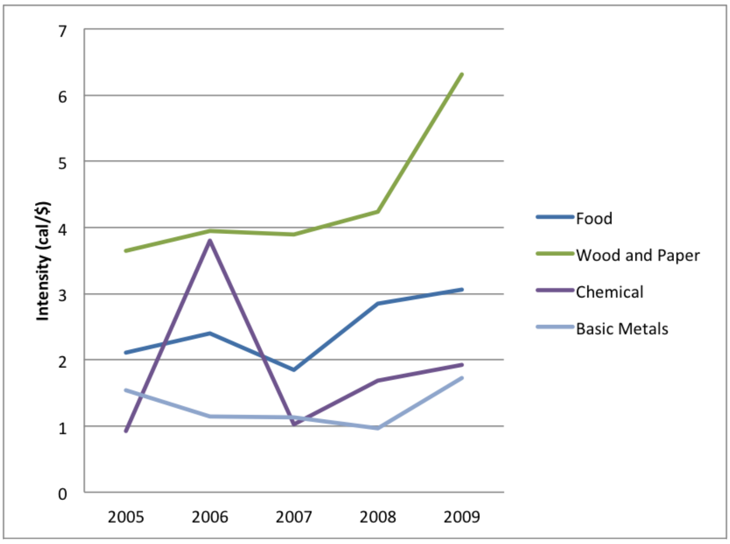

Figure 5.4: Energy Intensity by Sector

be explained by an important increase in natural gas consumption by a few firms during this year. Also, we see an intensity reduction in the year 2007 and an intensity increase in the years 2008 and 2009 in all sectors. This may be related to the economic downturn.

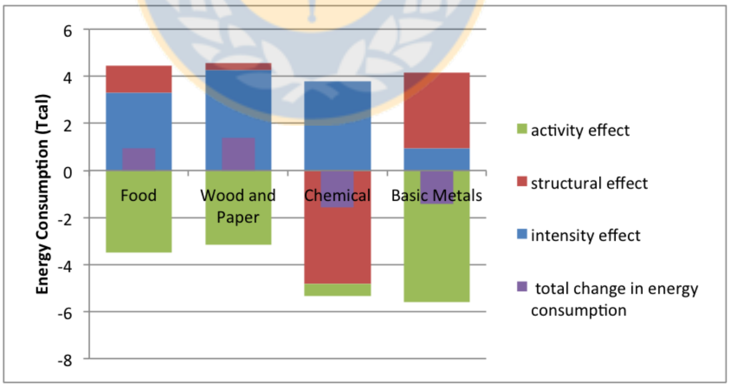

Figure 5.5: Decomposition by Sector

Figure 5.5 shows the decomposition of changes in energy consumption for the main industrial sectors. The results show an increase in energy intensity for all sectors, specially in the food, wood and paper, and chemical sectors. This intensity effect was counteracted by a negative activity effect. This last effect could be explained by a decreasin production level in all sectors, probably related to the general economic downturn.

Manufacture of Basic Metals

The Basic Metal Sector has the main participation both in production and in energy consumption of the Chilean industry. Figure 5.6 shows the decomposition of changes in energy consumption of this sector.

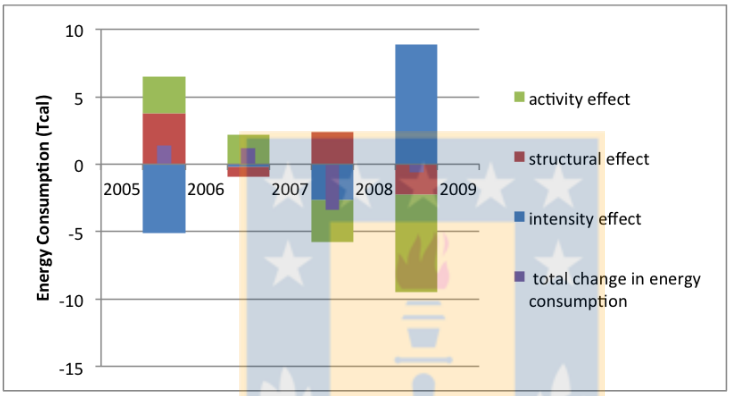

Figure 5.6: Basic Metals

The results show improvements in energy efficiency until 2008, in the last period 2008-2009 the intensity grows in substantial terms. Figure 5.10 shows changes in the price of copper. We can see that the price goes up in the period 2005-2006, then remains stable in the period 2006-2008, and falls down in the period 2008-2009. This behavior is inversely related to the behavior of energy intensity. This makes sense because the production was measured using the added value in monetary units, so if is price increases the added value grows and the energy intensity falls.

We discuss in the methodology section the strengths and weakness of physical indicators and economic indicators. The economic indicators, like the added value, do not allow to identify the real changes in production because the price effect can not be separated. However, we use the added value because of the data and, also, because it allows us to add different firms with different products.

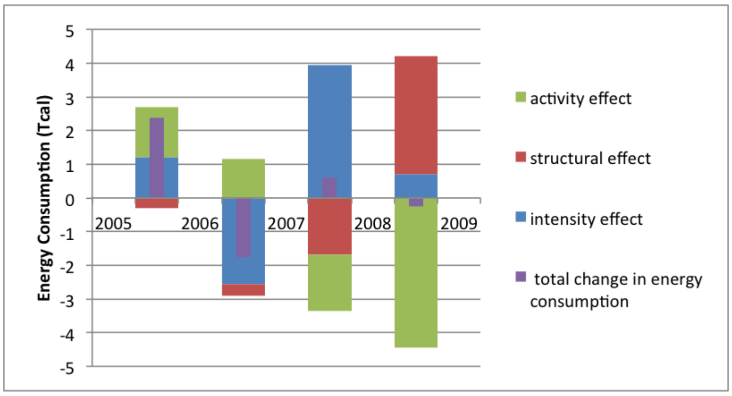

Figure 5.7: Food

Elaboration of Alimentary Products and Drinks

Figure 5.7 shows the decomposition of changes in energy consumption for the food sector. We can see that energy intensity falls in the period 2006-2007 but grows in the rest of the period, specially between 2007-2008.

Manufacture of Substances and Chemical Products

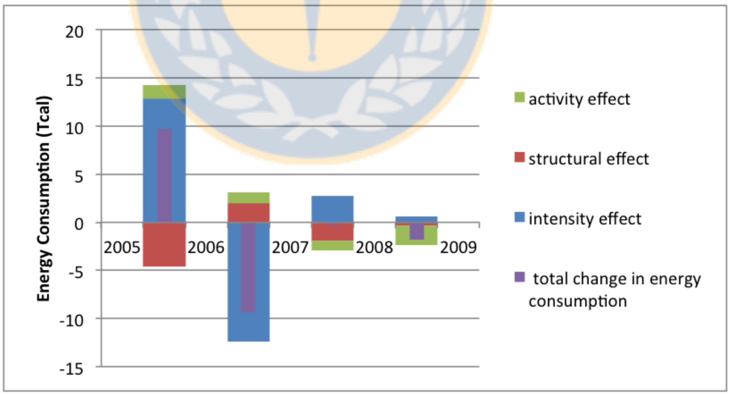

Figure 5.8: Chemical

Figure 5.8 shows the decomposition of changes in energy consumption for the chemical sector. We can see that energy intensity grows in the period 2005-2006, then falls in the period 2006-2007 and remains stable in the following years. We found that energy intensity grows up in the year 2006 because an increase in natural gas consumption in some firms.

Timber Production, Manufacture of Paper and Other Products

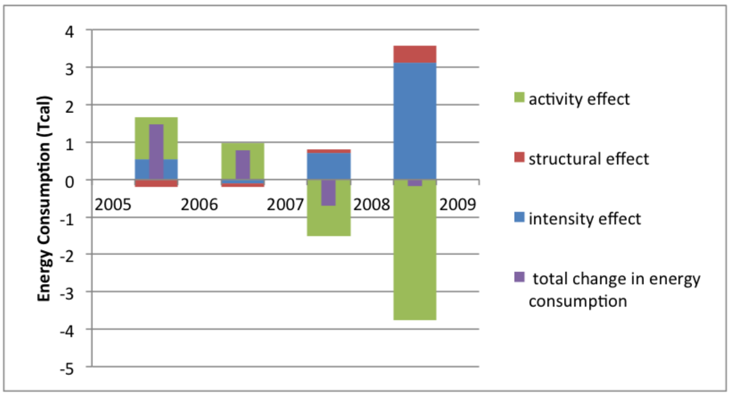

Figure 5.9: Wood and Paper

Figure 5.9 shows the decomposition of changes in energy consumption for the wood and paper sector. We can see that energy intensity grows slowly in the period 2005-2008 and then grows significantly in the period 2008-2009. Figure 5.10 shows that the pulp price falls down in the same period, this may be the reason for this sudden rise in energy intensity.

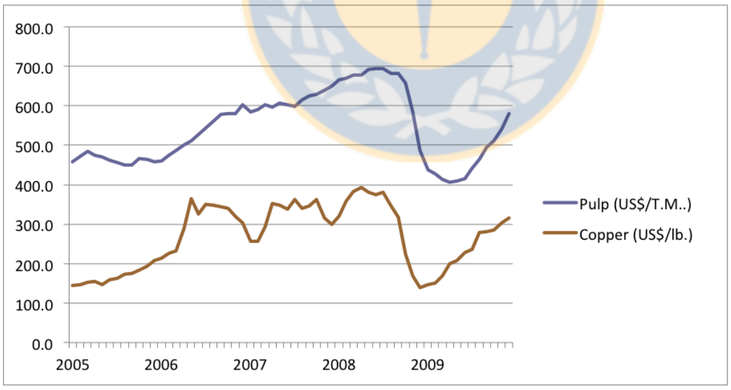

Figure 5.10: A Few important International Prices

Figure 5.10 shows the price development of copper and pulp for the period 2005-2009. Different studies found that energy intensity grows in economic downturns, when the level of production falls, [Balezentis et al., 2011]. In this study we found one possible explanation. We observed that, in some sectors, energy intensity grows when the price of its main product falls. This relation is clear if we use economic indicators, like the added value, and

	Number of Firms				
Size (number of workers)	2005	2006	2007	2008	2009
0 - 04	26	29	29	36	34
05 - 09	842	817	823	440	432
10 -19	1283	1172	1057	1042	1028
20 - 49	1629	1533	1443	1498	1367
50 - 99	743	756	699	722	694
100 - 199	484	463	456	433	407
200 - 499	357	351	360	360	311
500 - 999	110	103	120	97	96
> 1000	42	49	50	47	48

Table 5.1: Number of Firms by Size

we analyze sectors with a main product, such as copper in the basic metals sector or pulp in the wood and paper sector. In these cases when price decreases, added value falls, and energy intensity grows. If prices decrease during downturns, this could be the reason for an increase in energy intensity.

5.1.2 Decomposition Analysis by Size

The ENIA classified the firms by size according to the number of workers. Table 5.1 shows the number of firms by size, considering the number of workers. As shown in the table, most of the firms have less than 50 workers and only a small part have more than 500 workers.

Figure 5.11 shows the share in the total production and the share in the total energy consumption of firms by size. We can see that larger firms account for most of the production and energy consumption, and firms with less than 50 workers have an small incidence both on production and energy consumption

Considering the number of firms, and its participation on production and energy consumption, we classify the firms in:

- Small: firms with less than 49 workers
- Midsize: firms between 50 and 499 workers

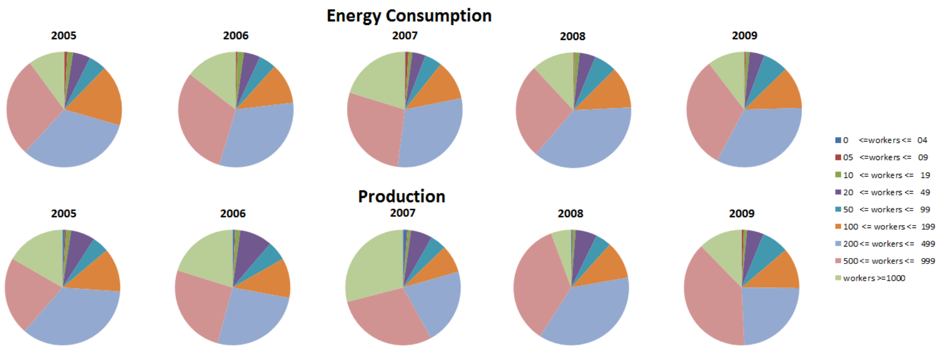

Figure 5.11: Energy Consumption and Production by Size

- Large: firms with more than 500 workers

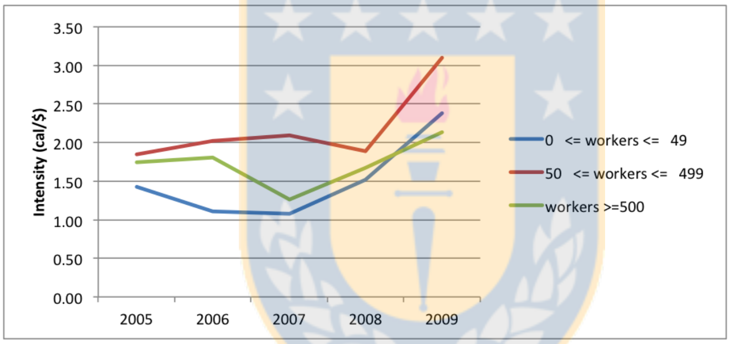

Figure 5.12: Energy Intensity by Size

Figure 5.12 shows the energy intensity of firms by size. We observe that small firms have a lower intensity than midsize firms, and close to the intensity of largest firms. This make sense if we considered that: small firms have a lot of manual work so energy intensity must be small, unlike midsize firms where an increase in mechanization means greater energy intensity and, finally, the large firms have economies of scale that reduce energy intensity.

Figure 5.13 shows the decomposition of changes in energy consumption by size. One can see that energy consumption remains almost stable in the period regardless of firms size. However, the intensity effect shows important losses, especially in the midsize firms rabge and, also but smaller, in big firms. This result is important to target policies toward less efficient firms .

Figure 5.14 shows the decomposition of changes in energy consumption for small firms. There are energy efficiency improvements until 2007 then

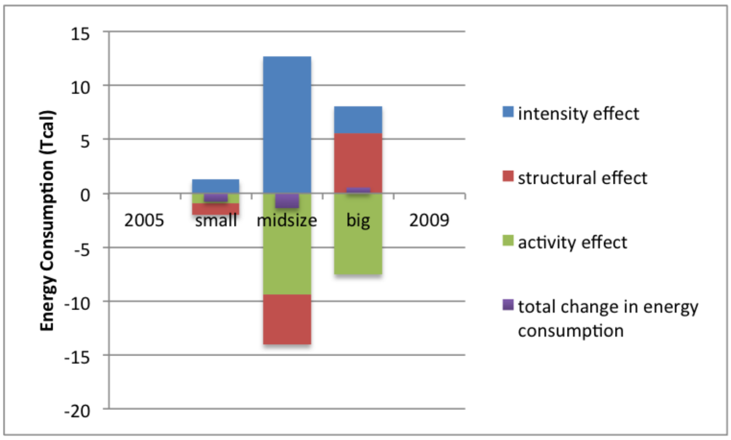

Figure 5.13: Decomposition by Size

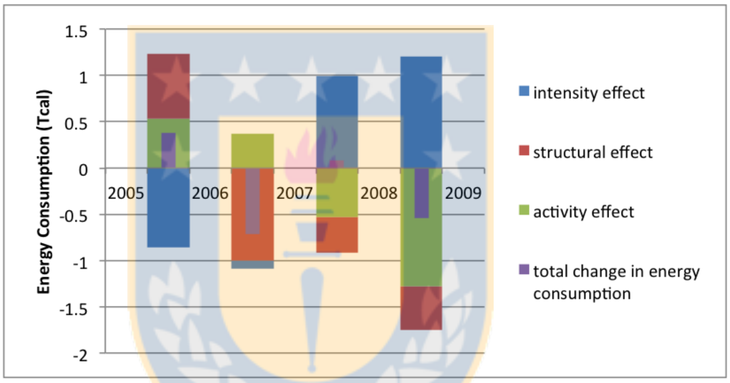

Figure 5.14: Small

energy intensity grows.

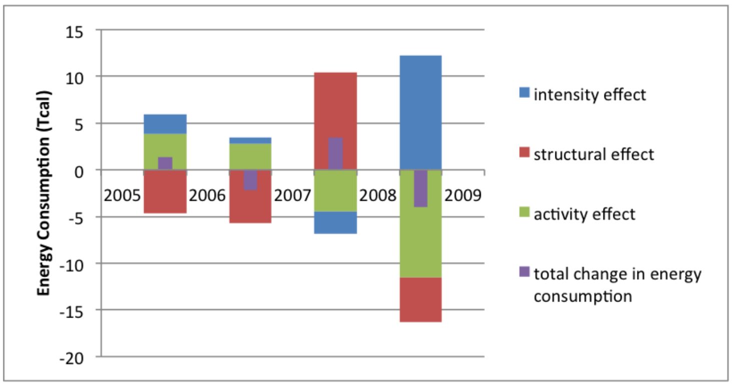

Figure 5.15: Midsize

Figure 5.15 shows the decomposition of changes in energy consumption for midsize firms. The most significant energy efficiency loss occurs in the period 2008-2009, this is probably explained for the economic downturn.

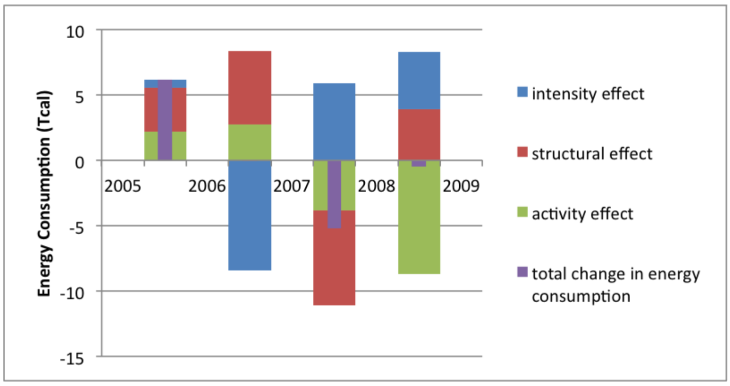

Figure 5.16: Big

Figure 5.16 shows the decomposition of changes in energy consumption for large firms. There are energy efficiency losses in almost all the periods. The structural effect for large firms has the opposite sign than structural effect for midsize firms. This effects shows that firms are moved through sizes .

Small firms have low energy intensity and are quite numerous. However, midsize and large firms respond for most of energy consumption and the largest losses of energy efficiency occurs in this group. Al this suggest that the main focus of public policies should be midsize and large firms.

5.1.3 Decomposition Analysis by Kind of Property

Table 5.2 shows the number of firms by kind of property. More than 90 percent of firms are national private. Meanwhile, a small group are foreign private, mixed and state. Mixed firms have national and foreign capital participation.

Figure 5.17 shows the participation on energy consumption and production of firms by kind of property. Although, national private firms account for most of energy consumption, other forms of property have participations exceeding the proportion of firms that represent. Especially remarkable is, the growing share of mixed firms on total production while keeping their share in energy consumption. Finally, state firms have a remarkable impor-

	Number of Firms				
Kind of Property	2005	2006	2007	2008	2009
National Private	5104	4870	4672	4274	4024
Foreign Private	169	176	153	185	183
Mixed	182	168	147	156	149
State-owned	61	58	65	60	61

Table 5.2: Number of Firms by Kind of Property

tance in terms of production.

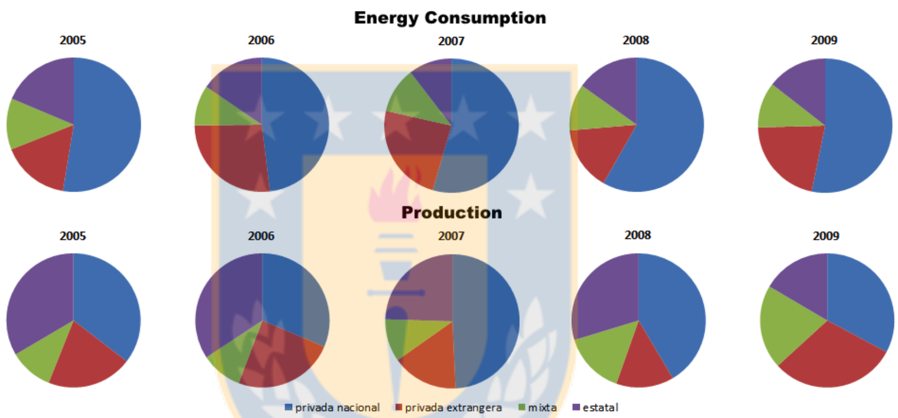

Figure 5.17: Energy Consumption and Production by Kind of Property

Figure 5.18 shows the energy intensity of firms by kind of property. State firms have an intensity below the others, this may be explained for higher returns, specially for firms that produce copper derivatives. Also, private national firms have a intensity above the rest. Finally, the intensity of mixed firms falls over period and the intensity of foreign firms remains stable. Possibly, because mixed firms are a result of technology incorporation.

Figure 5.19 shows the decomposition of changes in energy consumption of firms by kind of property. Despite that energy consumption remains stable in national private firms, there is a significant loss of energy efficiency. Foreign private and state firms show lower efficiency losses. While, mixed firms have a reduction on energy intensity, this means an increase in energy efficiency that explains a energy consumption reduction.

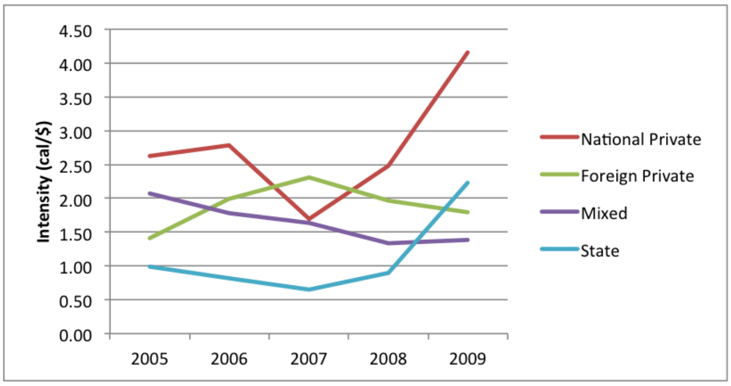

Figure 5.18: Energy Intensity by Kind of Property

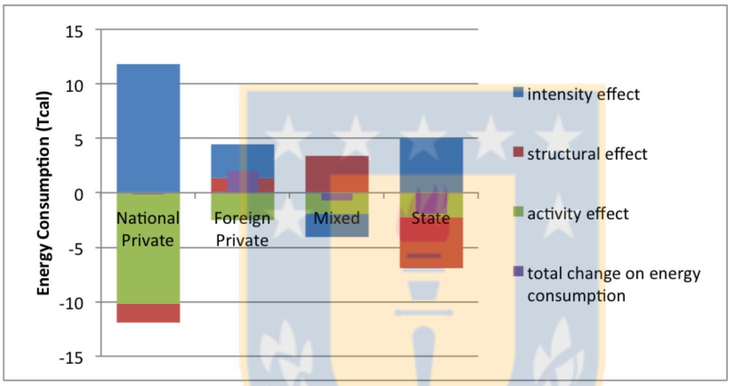

Figure 5.19: Decomposition by Kind of Property

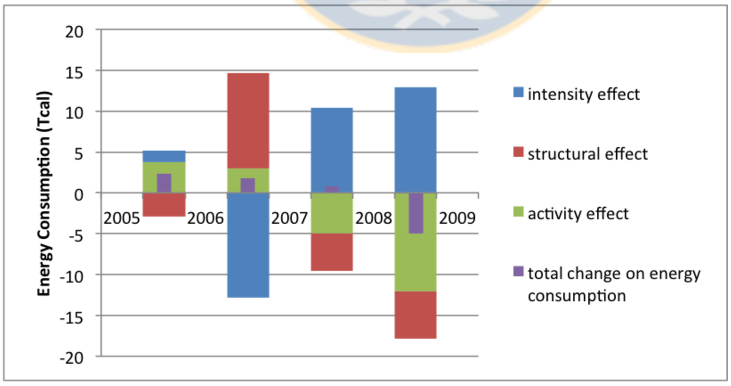

Figure 5.20: National Private

Figure 5.20 shows the decomposition of changes in energy consumption of notional private firms. The results show increases in energy intensity in most of the periods.

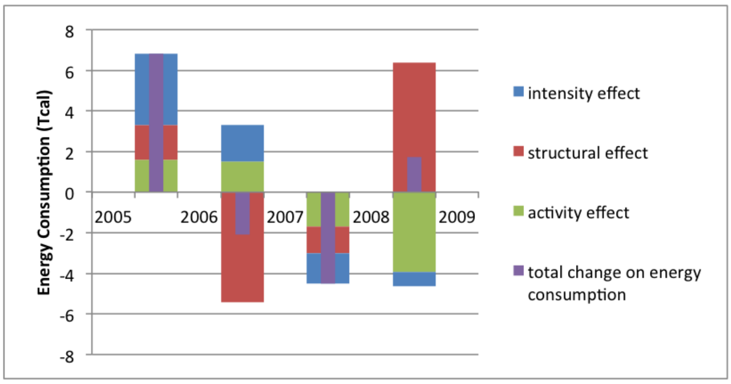

Figure 5.21: Foreign Private

Figure 5.21 shows the decomposition of changes in energy consumption of foreign private firms. The results show energy efficiency losses until 2007 and improvements in the following periods.

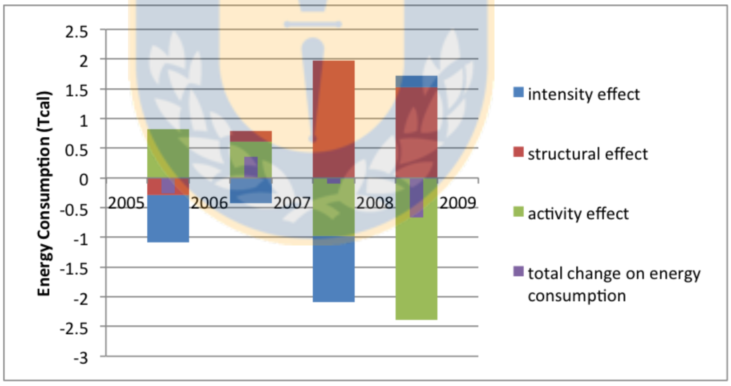

Figure 5.22: Mixed

Figure 5.22 shows the decomposition of changes in energy consumption of mixed firms. The results show energy efficiency improvements until 2008 and just a small loss of efficiency in the last period. Which are those firms? What are they doing?

Figure 5.23 shows the decomposition of changes in energy consumption of state-owned firms. The results show energy efficiency improvements until 2007 and losses henceforth. Stands out the large increase in energy intensity

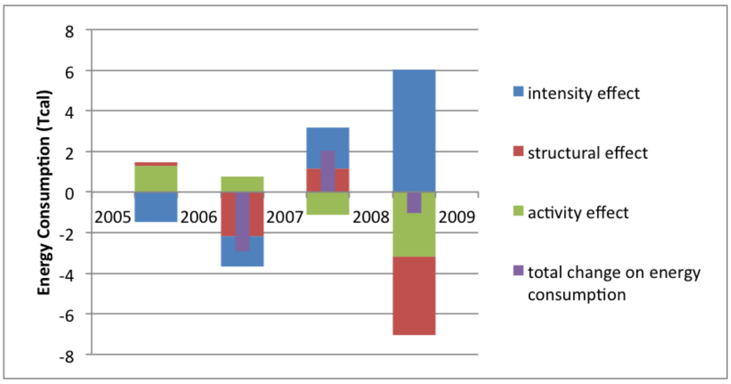

Figure 5.23: State

in the period 2008-2009.

In summary, more than 90 percent of firms are private national, although this firms account with most of energy consumption and production, the rest of the firms have an important participation, considering that they are just a few companies. Notably, the state-owned firms are few in number while their participation in energy consumption and production is large.

In this sense, one policy option is focus on state firms. These firms are few in number, have a large incidence on energy consumption and, in last years, show losses in energy efficiency.

In this sense, one policy option is focus on state firms. These firms are few in number, have a large incidence on energy consumption and, in last years, show losses in energy efficiency. This could be a previous stage, to define policies for the large and more heterogenous group, the private national firms. Also, is important to investigate mixed firms and what are doing to reduce energy intensity, a match analysis could be usefull.

5.2 Estimations

In this section, we use a panel data econometric approach in order to test hypotheses about the incidence of firms characteristics on energy intensity. We hoped that the panel approach would take account for the individual effects at firm level. The period 2005-2007 was used because in this period we can follow the firms over time. The variables and our hypothesis about its incidence are the followings:

- Size: Measured as the number of workers. The main hypothesis is that small firms have low energy intensity because they have many manual activities. Then, midsize firms grow in mechanization and reduced manual activities, so grows the energy intensity. Finally, large firms reduce energy intensity due to the scale economies. This hypothesis suggests a concave second degree relationship.

- Foreign Capital: Measured with a dummy variable that takes value 1 if there are presence of foreign capital and 0 otherwise. The hypothesis is that firms with foreign capital are less energy intensive than the others, because they follow international standars and have choose up-to-date technologies.

- Exports: Measured with a dummy variable that takes value 1 if the firm exports and 0 otherwise. The hypothesis is that exporting firms are less energy intensive than the others, because they must follow international standars.

Table 5.3 shows a description of the variables. The standard deviation is explained by two different deviations: the between deviation, the deviation over firms; and, the within deviation, the deviation over time. Our dependent variable, intensity, has a mean of 5.85 calory per Chilean peso and has a large variability over firms but mostly over time. Basic statistics of the explanatory variables show that only a 6.21 percent of firms has foreign capital participation and a 21.1 percent are exporting firms, most of the variability of these two variables is over firms. Firms have on average 84 workers, and the largest firm has 5745 workers, this variable moves over time and, mainly, over firms.

5.2.1 Full Model

Considering, the large variability of intensity over time and that Hausman test do not allows reject the nule hypothesis a random effects model was estimated. The results show that foreign capital and exportation are significative to explain highest energy intensity, this is not what we expected. Foreign capital was estimated at a high level of statistical significance, although with a positive sign. Exporting was also estimated with a significance better than 5 percent, but again with a positive sign. In the case of size the empirical evidence about a second degree relationship is quite poor, and the first degree

Variable		Mean	Std. Dev.	Min	Max
Foreign Capital	overall	0.0621	0.2414	0	1
	between		0.2316	0	1
	within		0.0630	-0.60	0.72
Size	overall	84.1220	204.3661	0	5745.00
	between		193.6985	0	3733.50
	within		60.5968	-1406.21	2322.78
Export	overall	0.2110	0.4081	0	1
	between		0.3934	0	1
	within		0.0981	-0.28	0.71
Intensity	overall	5.8578	112.9613	0	8458.16
	between		61.9618	0	2824.91
	within		91.4963	-2811.18	5639.10

Table 5.3: Description of Variables

Variable	Coefficient	t	P>t
Foreign Capital	16.26666	3.50	0.000
Size	-0.01807	-1.95	0.051
Size 2	0.00000	1.21	0.227
Export	5.90307	2.00	0.045
Constant	4.90001	3.88	0.000
Prob> χ^2	0.0002		
N	10217		

Table 5.4: Full Model Results

coefficient was estimated as negative. Thus, our data do not give support to our hypotheses, at least at an aggregate level.

5.2.2 Sectors

The inability of the data to provide a clear support for our hypothesis made us to wonder about a possible differentiated behavior by sector. Thus, we were interested in determine if the differences between sectors are significant. First, we estimate a model for each sector. Then, we use a likelihood-ratio testing the null hypothesis that the coefficients of a statistical model do not differ between different sectors.

Variable		Food Mean	Food Std. Dev	Wood and Paper Mean	Wood and Paper Std. Dev
Foreign Capital	overall	0.0666	0.2494	0.0469	0.2115
	between		0.2439		0.1982
	within		0.0646		0.0551
Size	overall	96.7862	242.8815	88.3068	171.4827
	between		241.6785		157.8010
	within		69.5696		41.2690
Export	overall	0.2428	0.4288	0.2202	0.4145
	between		0.4212		0.3984
	within		0.0854		0.1001
Intensity	overall	9.8033	136.2439	2.8275	20.6611
	between		75.1461		12.3038
	within		110.4356		15.9100

Table 5.5: Description of Variables by Sector

Variable		Chemical Mean	Chemical Std. Dev	Basic Metals Mean	Basic Metals Std. Dev
Foreign Capital	overall	0.2230	0.4165	0.1768	0.3819
	between		0.4036		0.3467
	within		0.1089		0.1080
Size	overall	112.3761	199.1609	231.7860	483.2817
	between		192.1752		417.7235
	within		53.2390		200.2771
Export	overall	0.3823	0.4863	0.4078	0.4922
	between		0.4693		0.4695
	within		0.1156		0.1284
Intensity	overall	11.2671	273.8877	14.0956	228.9296
	between		144.2020		119.8491
	within		223.0202		187.1307

Table 5.6: Description of Variables by Sector

	Food			Wood and Paper		
Variable	**Coefficient**	t	$P > t$	**Coefficient**	t	$P > t$
Foreign Capital	13.4301	3.46	0.001	0.9555	0.43	0.667
Size	-0.0105	-1.33	0.182	0.0041	0.66	0.508
Size 2	0.0000	0.66	0.508	0.0000	-0.43	0.668
Exportation	-0.5317	-0.22	0.825	0.6166	0.45	0.650
Constant	7.6793	7.01	0.000	2.1797	3.87	0.000
$Prob > \chi^2$	0.0095			0.6939		
N	3084			1498		

Table 5.7: Results of Model by Sector

	Chemical			Basic Metals		
Variable	**Coefficient**	t	$P > t$	**Coefficient**	t	$P > t$
Foreign Capital	-28.9234	-0.83	0.408	105.8217	2.11	0.035
Size	-0.2753	-1.44	0.148	-0.0921	-1.3	0.193
Size 2	0.0001	1.06	0.291	0.0000	0.99	0.321
Exportation	68.5859	2.03	0.043	19.1654	0.5	0.617
Constant	18.2017	0.92	0.358	8.7758	0.4	0.686
$Prob > \chi^2$	0.3037			0.1612		
N	599			304		

Table 5.8: Results of Model by Sector

Table 5.6 and Table 5.7 show a descriptive statistics for the variables by sectors. The intensity is larger in the Basic Metal sector and the Chemical sector. Also, foreign capital participation, exportation and size are large in these sectors.

Table 5.8 shows the estimation of a random model for different sectors. The sign of coefficients change over sectors. Foreign Capital is positive and estimated at a reasonable level of significance only for Food and Basic Metals. Size is negative for most sectors but is not significant enough for any. Exportating is positive for most sectors but is significant (at a level better than 5 percent) only for chemical sector. The Wood and Paper sector has a different pattern that is not captured by the model.

Table 5.9 shows the results of a likelihood ratio test. The test reject the null hypothesis, so the sectors are idiosyncratic. The Akaike Information

Model	Observations	ll(null)	ll(model)	df	AIC
Full	10217	-62287.29	-62271.92	10	124563.80
Food	3084	-16355.10	-16348.40	7	32710.80
Wood and Paper	1498	-6419.29	-6418.18	6	12848.37
Chemical	599	-4342.51	-4340.09	7	8694.19
Basic Metals	304	-2144.54	-2141.27	7	4296.54
LR chi2(17)	66047.94				
$Prob > \chi^2$	0.0000				

Table 5.9: Likelihood Ratio Test

Criterion (AIC) says that the model fits better for the Basic Metal sector and then with the Chemical sector.

In summary, energy intensity is idiosyncratic by sectors. This have policy implication because suggests sectorial policies. The characterization of some sectors, particulary Wood and Paper, needs more effort because the models do not captured its pattern behavior. Foreign capital was estimated as significant. However, the causality is not clear. The intensity is high in foreing firms or foreign capitals choose most intensive sectors, like Chemical and Basic Metals sectors.

Chapter 6

Conclusions

Chilean industry is the largest energy consumer within the country. Energy demand has been growing fast and future energy supply is uncertain. In this context energy policy has taken a crucial importance in Chile and sectorial policies for the main consumer - industry - are an option to consider.

Decomposition analysis is a useful tool to have a picture of what happens regarding energy consumption and energy efficiency in Chilean industry. The LMDII was used to break down energy consumption and find the relative importance of energy intensity changes.

The results show that energy consumption remained almost constant during the period under study, while energy intensity grew significantly. Energy consumption did not grow because of a falling output level. This fact is important because then the idea of a decoupling between output and energy consumption seems wrong and probably energy consumption keep growing when the economy recovers.

The industrial sectors are idiosyncratic. Energy consumption and energy efficiency follow different patterns, but all sectors shows energy efficiency losses. All sectors need policies that promote energy efficiency, and differentiated sectorial policies are preferable to a single policy.

In sectors with a dominant product –basic metal and wood and paper– energy intensity follows a counter-cyclical trend than that of the price of the product. This could explain the fact that energy intensity grows during downturns. This behavior was observed not only in Chile, but it is a recognized fact in previous studies in other economies. In this sense it is important to find a way to separate the price effect of the energy intensity.

In terms of size, midsize and large firms have the largest losses in terms of energy efficiency. Small firms are large in number but small in terms of energy consumption. So focusing energy policies in midsize and large firms seems appropriate.

State-owned firms are few in number, though they have a large incidence on energy consumption and, during the few last years, showed losses of energy efficiency. Under these considerations, a policy focusing on state-owned firms as a previous stage to broader approach could be useful.

Finally, the causality of the relationship between foreign capital and energy intensity is not clear. The results show that firms with foreign participation have more stable energy intensity than national firms; even mixed firms (with national and foreign capital participation) show improvement in terms of energy efficiency during the period. A deeper analysis is required to understand the incidence of foreign capital in energy intensity; a matching analysis to find comparable firms could provide a better idea about this subject.

This research provides a good picture about energy consumption in the Chilean industry. However, future efforts must be done to understand the energy intensity in each sector, isolating the price effect from energy intensity, understanding the impact of foreign capital in energy intensity and extend the analysis to a longer period.

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