Nanoscale Reports

RESEARCH ARTICLE

DOI:10.26524.nr.5.7

5(3) (2022) 1-13

OPEN ACCESS

Chilean Export of Lithium Carbonate: Production Chain and Market Variables

Daniel Alamos-Pichuncheo [1], Barbara Valenzuela K [2], Andrés Soto-Bubert [1], Roberto Acevedo[1*]

Abstract

The lithium carbonate, presents an increase in price and demand, however, there is not studies where an equation is proposed that allows modeling the Chilean exported behavior of the mineral. This study is put forward an equation that allows to model the lithium carbonate exports in addition to identify the most influence variables in the commercial exchange of that product between two countries, using the extended gravitational model. The estimated model is not consistent with the gravitational model theory. This is because lithium carbonate is a manufacturing input and the costs of transporting and importing do not influence the volume that is imported. This research has opened new study proposal; such as improve the lithium carbonate export estimation taking into consideration the problem of zero observations.

Keywords: Chile; Lithium Carbonate; Export; Gravity Model..

Author Affiliation: [1]Facultad de Ingenierìay Tecnologìa, Universidad San Sebastián, Bellavista 7, Santiago-8420524, Chile.
[2]Unidad de Postgrado y Negocios, Universidad Mayor, Manuel Montt 367, Santiago-8340589, Chile.

Corresponding Author: Roberto Acevedo.Facultad de Ingenierìay Tecnologìa, Universidad San Sebastián, Bellavista 7, Santiago-8420524, Chile.

Email: roberto.acevedo@uss.cl

How to cite this article: Daniel Alamos-Pichuncheo, Barbara Valenzuela K, Andrés Soto-Bubert, Roberto Acevedo. Chilean Export of Lithium Carbonate: Production Chain and Market Variables 1-13.
Retrieved from https://nanoscalereports.com/index.php/nr/article/view/86

Received: 12 March 2022 **Revised:** 15 April 2022 **Accepted:** 27 May 2022

I.INTRODUCTION

The world advances by leaps and bounds in the implementation of renewable energies in everyday use and that is where lithium is one of the main protagonists due to its application in batteries, especially with a view to electro mobility. As for reserves, Chile has an outstanding participation in this market with the 48 % of the world total (USGS, 2018) in the Salar de Atacama, which also has geological conditions and especially favorable climate for the production of lithium minerals. Within these conditions is its great extension, its low precipitation rate, its high temperatures, the low humidity in the environment, the presence of wind in the area, in addition to the high concentration of lithium, potassium and low lithium-magnesium ratio. The lithium carbonate, the main product lithium exported by Chile, presents a clear trend towards an increase in both price and demand, however, have not been documented studies where an equation is proposed to allow modeling the export behavior of the mineral. According to this and given the importance of lithium carbonate, this study aims to propose an equation, through a descriptive, exploratory and empirical study, which allows to model the exports of lithium carbonate, in addition to identifying the variables that most influence in the commercial exchange of said product between two countries.

To meet the objective, the gravitational model is proposed, estimating lithium carbonate exports using static and dynamic panel data. Finally, a section of conclusions is added where we proceed to interpret the results obtained in the modeling, both general and specific for each of the resulting significant variables. There are no articles with this methodology in Chilean literature.

2. World Resources and Reserves of Lithium

The United States Geological Survey (USGS) (2017) has estimated a total reserves of 15,556 tons of lithium, within a resource universe of 47,000,000 tons. Chile ranks third in the amount of lithium resources, with a total of 16%, placing itself behind Bolivia and Argentina that own 19% of the total planet. However, when talking about lithium reserves, Chile tops the ranking with 48% of total, followed by Argentina with 14% and Australia with 11% (COCHILCO, 2017).

The mining reserves according to Codelco (2016) “represent the subset of the mineral resource measured and indicated and that is removable according to a technically and economically sustainable mining plan, inserted in a productive scenario”. According to the above mentioned and applying it to the lithium scenario, the reserves are defined by various factors such as climate, geographical location, lithium concentration, salary extension, among others. Table 3 describes the variables.

In Table 4 you can compare different salt mines around the world organized from highest to lowest lithium content. The data allow us to understand the magnitude of the operations of these salt flats and infer part of the reasons why, in some salt flats, a lithium extraction project has not been developed from the brines present there. Currently, Chile›s production is clearly focused on the Salar de Atacama which, according to table 4, presents the best conditions, both geological, climatic and geographical for brine extraction and salt production. Its 3,000 square kilometers of extension make it one of the largest salt flats in the world with lithium content. In addition, there is a greater concentration of lithium and potassium in the sector, which allows obtaining brines rich in lithium, in addition to the parallel production of potassium salts. Also, the amount of magnesium compared to that of lithium represents an approachable relationship when obtaining the product of interest, without making the process too expensive.

On the other hand, the climate present in the solar; considering solar radiation, air humidity, wind currents and temperature conducive and a good evaporation rate, which, together with low rainfall, 27.8 mm. annual present in the area, has one of the place most favorable worldwide to define the path of preparation by solar evaporation. Finally, its location geographical ends up making the Salar de Atacama the best place for the extraction of lithium and it is located relatively at low altitude and at only 270 km. from the port of Antofagasta, making it easily accessible. The conditions mentioned above allow the cost of production of lithium carbonate in the Salar de Atacama to present lower operational costs compared to other salaries in the world, increasing the profit margin. It is worth mentioning the other salt flats present in Chile, which, although they do not have the same characteristics as the Atacama room, have conditions that merit further studies to evaluate the feasibility of lithium extraction from their brines.

2.1 To Extraction process from lithium brines

Extraction of the important sources of lithium extraction are brines, which are particularly important for South America and that the known «triangle lithium» is composed of areas rich in brines with high concentrations of this element. This concept of the lithium triangle, plotted in Figure 2, covers part of Argentina, Bolivia and Chile and contains the largest lithium reserves worldwide.

2.1.1 Pumping and evaporation

The specific process applied in Chile begins with the extraction of the brine from an approximate depth of 30 meters towards the surface by means of pumps. Brines with approximately 0.23% lithium are sent to solar evaporation wells, where after several stages, a concentration of approx. 5.8% lithium. This operation takes approximately one year (González, 2000).

The extraction of lithium by solar evaporation has a fairly simple and low-cost operation, but it also has many technical requirements and can present many problems. For a correct operation you need large areas of flat land for the construction of the pools, in addition to the necessary conditions to evaporate the water from the pools.

The evaporation rate is controlled by solar radiation, air humidity, wind and the present temperature, therefore, these variables influence the size of the pools, the final concentration of the brine, the cost of the pools and their operation and in the treatment of the final brine.

To have a better cost-effectiveness ratio, the pools should be divided into segments to maximize the evaporation rate (the rate decreases as the concentration in the brine increases), so, ideally, in each pool crystallizes a different salt that must be removed periodically without disturbing the entire system, that is, without affecting the precipitation process.

Other important aspects when designing evaporation pools are to consider a gravitational flow from one pool to another to optimize energy expenditure; protect the edges of the pools against erosion caused by brine waves; and most importantly, create a leak-free solar protection system. The pools are built on the salt flat with a layer of fine gravel and clays, and then covered with a 0.5 mm waterproof PVC membrane of thickness. Then, above all this, a special layer is installed that protects from tillage machinery and the action of ultraviolet rays (Garret, 2004). During the evaporation process, Halita ($NaCl+CaSO_4*2H_2O$) precipitates first, then Silvinita (which is sent to the potassium chloride plant, then Carnalita (NaCl+ KCl) and finally Bischofita ($KCl*MgCl_2*6H_2O$) precipitates. In addition, Lithium Carnalite ($LiCl*MgCl_2*6H_2O$) can precipitate, which it is recovered by drainage, repulping and subsequent washing with saturated. (Gonzalez, A., 2000).

2.1.2 Chemical plant

The product, from evaporation pools with approximately 5.8% lithium, is sent to the chemical plant where Mg is removed to obtain a brine with approximately 6% lithium. To reach the final product is added in hot, causing precipitation, which is filtered and dried in rotary kilns for battery grade, having a purity of 99.5% (Albemarle, 2014), the minimum required by the market 99.1% (Ministry of Economy and Public Finance of Argentina, 2011).

In parallel, the metal lithium industry requires as a raw material with low Boron content. This is why before sending it to the chemical plant, a process that reduces the boron content to 10 ppm is applied. The process consists in purifying the brine by removing the boron for a subsequent manufacture of boric acid.

2.2 Lithium World Market

This chapter details the main producers of lithium carbonate worldwide, describes part of the history of the two companies that currently produce lithium carbonate in Chile, in addition to presenting exports of other lithium-derived compounds and the most important buyers. Finally, the income generated by lithium to the national economy is presented.

2.3 Global Lithium Reduction

Currently, worldwide lithium production is based on the extraction by the two routes mentioned above. Argentina, Bolivia, Chile, China and the United States are carrying out developments for the extraction of lithium from brines, while Australia, Austria, Canada, China, Spain, Finland, Mali, Portugal and the Czech Republic are developing profitable mineral extraction techniques from espodumeno (USGS, 2018). The world market, as indicated in table 5, is mainly led by four actors: Australia, Chile, Argentina and China.

As can be seen, Australia increases its production significantly from 2016 to 2017, moving from second place to being the world leader in lithium production. For its part, Chile, who was the world›s largest producer until 2016, shows a slight decline.

In this way, the aforementioned data help to represent the worldwide distribution of world lithium production in 2017.

2.4 Production of Lithium in Chile

As of 1979, by decree of law N 2. 886, the lithium is reserved for the State of Chile with two exceptions: it did not extend to existing belongings and that had a written record of measurement; or that were in process for the year of publication of the decree of law.

In 1982, Organic Law No. 18.097 on mining concessions was published, followed by Law No. 18.248, corresponding to the Mining Code of 1983, which maintained the reserve of lithium in favor of the State of Chile and ratified that Lithium is not susceptible to mining concession, except for those already established prior to the date of publication of Decree No. 2,886.

At the time of entry into force of Decree No. 2,886 CORFO has a total of 59,820 mining belongings in the Salar de Atacama.

Chile has four commercial products based on lithium: lithium carbonate, lithium chloride, lithium hydroxide and lithium brines. The following graph details the production of Chile according to the type of compound between 2009 and 2016, where the decreases may be due to the economic crises of 2009 as occurred in Europe during 2013-2014. As an interesting observation, it is appreciated that lithium production, although it has highs and lows, always tends to increase.

Clearly, much of the Chilean lithium production in recent years corresponds to lithium carbonate, in fact, it is the only compound where exports over the years have a behavior clearly similar to that of total production, therefore, it is the one who marks the trend behavior. However, although production has been variable within the years, lithium carbonate has a clear tendency to increase within the country›s global productions, as shown in table 6.

According to the data of the Chilean Copper Commission (COCHILCO), the countries that stand out in the acquisition of lithium carbonate (Chile›s main export product based on lithium) are historically: South Korea, Japan, China, Belgium, United States and Germany. As Figure 5 shows, lithium carbonate produced in Chile is mainly destined to countries in the Asian continent, which according to Figure 6, have a clear tendency to increase investment to acquire the lithium ore produced in Chile.

2.5 Revenue from exports of lithium carbonate

Fig. 7 shows the large amount of income from lithium carbonate compared to the other products derived from the same element.

Table 7 shows the evolution of total lithium carbonate exports between 2005 and 2016, in addition to the thousands of dollars exported in each year for the sale of the product. With these data, the mathematical relationship is made to obtain the average value is FOB (up to Chilean port) through the years 2005 to 2016.

In Figure 8, it is displayed how Chilean exports not depend on the value of FOB lithium carbonate. In addition, it is observed how lithium carbonate has a tendency to increase its value over time, especially during the last 3 years. The great increase in value that the product has had is remarkable, since, according to table 7, the FOB value of lithium carbonate has increased more than 3 times in only 11 years and, in addition, the year 2016 has increased by 42% in relation to the value it had in 2015.

In the same way and according to the data presented by COCHILCO (2017), the distribution by total export amount of lithium carbonate according to destination country is found in Figure 9.

Through data tonnes of lithium carbonate exported in 2016 and amounts and exports in thousands of dollars in 2016 corresponding to that product, it may be realizer an estimate of the price of selling ton of lithium carbonate to the most important buyers. When analyzing Table 8, the relationship between the amount of lithium carbonate exported and the thousands of dollars obtained from said commercial exchange, since the countries that most buy Chilean lithium carbonate, are not precisely those who pay a lower unit price per the China, which is the second buyer of lithium carbonate, in 2016 paid 89% more than Germany, which only acquires about a quarter of what the Asian country acquires.

The increase in the production of lithium by Chile, added to the rise in the price of the element and its associated minerals, together with the growing demand, has led to this mineral becoming increasingly protagonist within the national economy, reaching to represent 1.2% of the country›s income in 2017, surpassing exports of non-mining products such as avocados and closely following the total produced by meat exports, as shown in Figure 10.

3. Model and Estimation

This research uses an extended gravitational model, using pool and static panel data with fixed, random and dynamic effects (Arellano-Bond and Arellano-Blundell), in order to analyze the variables that affect the export of lithium carbonate between the years 2005 and 2016. This model refers to Newton›s model that relates the attraction between two bodies according to their masses and the distance that separates them, where the attraction is proportional to the masses of the bodies and inversely proportional to the distance that separates them. In its economic version, the masses are replaced by the size of each country›s economy, or gross domestic product (GDP), while the separation distance is an estimate of transportation costs. The character of «extended» is given because in addition to GDP and distance, more variables are added that can influence when exporting lithium carbonate.

The first authors who use the gravitational model to analyze international trade were Tinbergen (1962), Pöyhönen (1963) and Linnemann (1966). In the studies of Anderson (1979), Bergstrand (1985) and Helpman and Krugman (1985), gravitational equations are derived from international trade models based on product differentiation and yield on an increasing scale, and theoretical support was provided rigorous. Mátyás (1997), Cheng and Wall (1999), Bayoumi and Eichengreen (1998), Breuss and Egger (1999), and Egger (2000) provide econometric specifications. In recent decades, the extended gravitational model is one of the models that has been most used to analyze the flows of international trade, migration or foreign investment, due to its properties, its theoretical and empirical support, and its flexibility and adaptation to different regional realities or to that of a particular country.

This work includes the 14 most important countries in the export of Chilean lithium carbonate, these countries are: China, South Korea, India, Japan, Thailand and Taiwan (considered separately from China due to its complex political relationship with that country), corresponding to Asia; Germany, Belgium, Spain and Italy of Europe; Canada and the United States of North America; Mexico of Central America; Argentina from South America. To select these countries, those that do not have more than five observations or 0 regarding the importation of lithium carbonate by Chile are considered within the study period. Exports to these countries represent 99% of lithium carbonate exports within the study period (2005-2016). The simplest form of this equation, which seeks to determine the trade between two countries (i, j), is given by equation 1:

$$E_{ij} = \alpha_0 Y_i^{(\alpha_1)} Y_j^{(\alpha_2)} D_i j^{(\alpha_3)}$$

where it Y_i represents the GDP of the exporting country, Y_j represents the GDP of the importer and D_{ij} is the distance between the two countries. According to the theory, GDP is directly proportional to trade between countries, while the distance is inversely proportional. Indices α_0, α_1, α_2 and α_3 are unknown parameters. In order to eliminate the heteroscedasticity present in the sample and according to commercial literature, the variables are expressed in natural logarithm.

The estimation strategy to model equation (1) is to use a methodology that allows considering the dynamic effect of lithium carbonate exports. The importance of using this kind of methodologies is that it makes it possible to obtain long-term elasticities that take into account the autoregressive effect derived from the presence of some continuity in the export markets between Chile and the countries of study: once the commitments between the parties and export begins, generally these commitments remain in force for several years (Perroti, 2015). Because the estimators of ordinary least squares, fixed effects and random effects are biased and inconsistent for this type of model (Baltagi, 1995), together with the fact that Chile›s export behavior is dynamic and fluctuating according to Fuenzalida-O›Shee , Valenzuela-Klagges and Corvalán-Quiroz (2018) is estimated according to the Arellando method. According to the above, the following model is determined:

Where it β_0 is a constant for each pair of merchant countries, it(E_{ijt-1}) is the first delay of the dependent variable and (E_{ijt-2}) is the second delay of the same. Further: they represent the exporting country, the importing country and the year, respectively;

i,j y t represents the export flow from country i to country j;

E_{ij} it is the gross domestic product of country i and j, respectively;

$\gamma_{(i,j)}$ it is the maritime distance between country i and country j in kilometers;

ε_{ij} represents the sale price to country j;

θ_j is the price for exporting (i)/importing (j) a 20 foot container in US dollars;

$\mu_{(i,j)}$ represents the relationship between the conversion factor of the purchasing power parity of country I, j, and the market exchange rate;

$\tau_{(i,j)}$ it is the index of perception of corruption in country i, j;

$\phi_{(i,j)}$ represents the democracy index of the exporting and importing country, respectively;

$\upsilon_{(i,j)}$ It represents exports of high-tech products from the exporting country, Chile, in year t. In addition, equation (2) includes dummy variables represented by ($\sum_k \varphi_h P_{ij}$), those that take a value of 1 in case they apply for that country / period and 0 in case they do not.

In the estimations all the aforementioned variables were considered, however, during the estimation process the variables that do not present statistical significance within the model are discarded. According to the above, the variables that have shown a significance within the model are described in detail:

-L distance between countries considered for the model is given by the sum of 0.94 km. corresponding to the distance between the square of Antofagasta and the port of the same city, plus the maritime distance between countries and the distance between the port and the capital of the country of destination.

-The price for importing container corresponds to the value that each country must pay to make a 20-foot container enter the national territory. The price varies according to each importing country and according to each year.

-The conversion factor of the purchasing power parity of a country and the market exchange rate has been added because it represents the amount of units of a national currency that are required to acquire the same amount of goods and services in the country. national market that could be acquired with United States dollars in that country. Therefore, it matches the economies of the pairs of countries under study to the same unit.

-The export of high-tech products refers to the export of products made with high standards of research and development, such as products from the space, computer, pharmaceutical, scientific instruments and scientific machinery industry.

This variable has been studied only in the case of the exporting country, Chile, since the lack of data for the Republic of China, Taiwan, does not allow it to be applied to importing countries. The results obtained from the estimation using the Arellano-Bover / Blundell-Bond model with two delays are presented in Table 9.

Note 1: Values with heterocedasticity and corrected endogeneity.

Note 2: Level of significance: *** = 0% error;** = 0% <P ≤ 2.5%;* = 2.5% <P ≤ 5%

Note 3: The values in parentheses represent the error standard.

According to the data obtained, the proposed model is expressed as follows for the years 2005-2009 and 2013-2014:

$$\ln(E_{ijt}) = -39{,}64 + 0{,}42\ln(E_{ijt-1}) + 0{,}22\ln(E_{ijt-2}) - 1{,}56\ln(\gamma_{it}) + 2{,}02\ln(\varepsilon_{ij}) + 0{,}69\ln\mu_{jt} + 0{,}57\ln\tau_{jt} + 1{,}27\ln\psi_{it} + \omega_{ijt}$$

In addition, for the years 2010, 2011 and 2012 a value of 0.61 must be added, while for the years 2015 and 2016 a value of 0.49 must be added.

An obtained time or the model, it verifies their efficiency by replacing the data in the equation and comparing the result with actual exports and s. The first graph, figure 11, shows the result of said exercise having all the data in natural logarithm.

The previous figure shows a very close behavior between the export values in natural logarithm, real with estimates using the equation. El 2007 has a high error compared to other years due to the influence of values 0 (zero) as mentioned by Santos and Tenreyro (2006). An exports for 2005 and 2006 cases arise where there is no documented export which means the delay effect strongly affect the year 2007. By excluding said year and calculating the average error, 0.84% is obtained. However, if this exercise is replicated to tons values and not in logarithms, a significant increase in the estimation error is observed, as can be seen in Figure 12. When calculating the average estimation error, excluding the year 2007, a significant increase is observed, reaching a percentage of error of 34%. This is due to the fact that, as expressed by Santos and Tenreyro (2006), the data considered as 0 in the study, cause a decrease in the coefficients of the equation generating an estimate with a similar behavior, but with much smaller values.

Table 1. Observations lithium in nuclear fusion reactors

AUTHOR (ES)	YEAR	OBSERVATIONS
World Nuclear Association	2017	"Lithium-7 has two important uses in nuclear energy today and tomorrow due to its transparency relative to neutrons. As hydroxide it is necessary in small quantities for safe operation in the pressurized water reactor (PWR) cooling systems as a pH stabilizer, to reduce corrosion in the primary circuit. As fluoride, it is also expected to have a much higher demand in molten salt reactors (MSR)."
National Lithium Commission (Chile)	2014	"The CChEN watches over the nuclear interest of lithium in a long-term perspective, authorizing each producer in a restricted way the amount of lithium equivalent to commercialize and controlling that the destinations are not producers of the isotope, of main interest in the generation of tritium."
Chilean Copper Commission (COCHILCO)	2013	"Regarding the nuclear interest, lithium has been considered as a fundamental material for the development of nuclear fusion reactors, whose future is still uncertain and in full stage of research and development. There is still no certainty if it really is a viable source of energy for mass consumption and when it might be expected to be commercially used. However, it is estimated that only in the second half of this century would the construction of the first commercial reactors begin, which could eventually cause a temporary narrowing of the lithium supply."

Table 2. World lithium reserves.

Market Stall	Country	Reservations (ton)	Percentage (%) Total
1.	Chile	7,500.000	48.18
2.	China	3,200.000	20.56
3.	Argentina	2,000.000	12.85
4.	Australia	2,700.000	17.35
5.	Portugal	60.000	0.39
6.	Brasil	48.000	0.31
7.	US	35.000	0.22
8.	Zimbabwe	23.000	0.15
	Total	15,566.000	100.00

Table 3. Key factors in the viability of a salary.

Variable	Effect
Lithium concentration	Decide on the amount of lithium recoverable salts.
Salt area	The extent of a salt determines the amount of brines available.
Potassium concentration	Potassium is a co-product of lithium extraction and increases the profit margin, lowering operational costs.
R elation between magnesium and lithium	A higher concentration of magnesium increases the consumption of lime to precipitate Mg and / or when a greater surface area of solar evaporation is required to concentrate the magnesium salts and separate them by crystallization, making the recovery of lithium more expensive.
Weather	An arid climate is required for the use of solar evaporation as an extractive method; that is, the precipitation rate must be much lower and the evaporation rate higher.

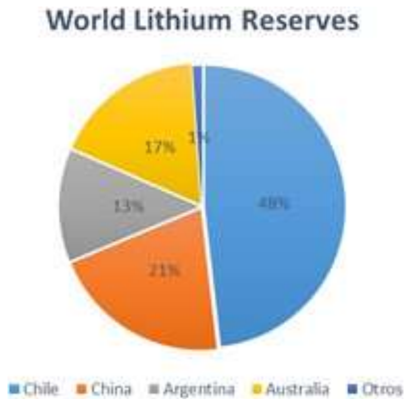

Fig. 1 Distribution of world lithium reserves

Table 4. Comparison of major salt factors in the world.

to Salt	country	Li (ppm)	K (ppm)	Mg / Li	Evaporation (mm / y)	Surface (km2)	Height (masl)
Atacama	Chile	1,500	18,500	6.4	3,700	3,000	2. 300
Large Grasses	Bolivia	1,033	7,766	2.2	1,500	100	4,200
The island	Chile	860	3,170	5.1	1,000	152	3,950
Maricunga	Chile	800	7,480	6.6	1,200	145	3,760
Salinas Grandes	Argentina	795	9,547	2.7	2,600	212	3,450
Olaroz	Argentina	690	5,730	2.4	2,600	120	3,900
Dead man	Argentina	690	6,100	1.4	2,775	600	4,300
Zhabuye	China	680	s / a	0.001	2,300	243	4,420
Flint	Chile	400	4,200	8.7	1,200	335	3,370
Cauchari	Argentina	380	3,700	2.8	2,600	350	3,950
Uyuni	Bolivia	350	7,200	19	1,500	12,000	3,650
Corner	Argentina	330	6,200	8.5	2,600	260	3,700
Silverpeak	USA	230	5,300	1.5	900	80	1,300

Fig. 2 Lithium triangle

Table 5. World production of lithium (tons)

	2016	2017
AUSTRALIA	14000	18700
CHILE	14300	14100
ARGENTINA	5800	5500
CHINA	2300	3000
ZIMBABWE	1000	1000
PORTUGAL	400	400
BRAZIL	200	200

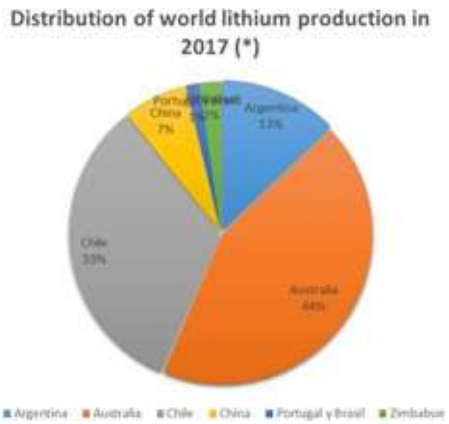

Fig. 3 Distribution of world lithium production in 2017

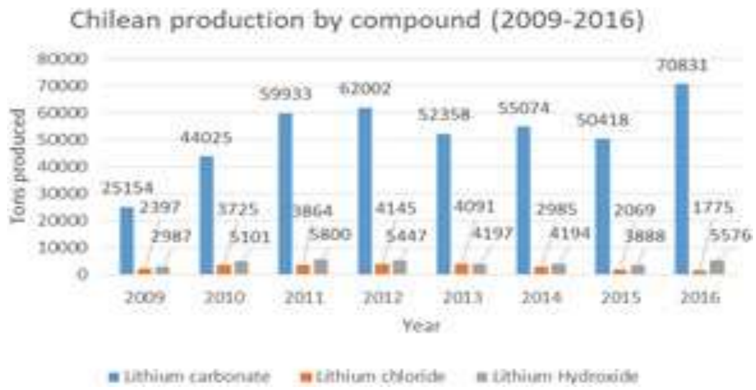

Fig. 4 Chilean production by compound 2012-2016

Table 6. Percentage of lithium carbonate in the global production of Chile.

Year	Lithium products (tons.)	Lithium carbonate (tons.)	% of lithium carbonate in total
2009	30,538	25,154	82.4%
2010	52,851	44,025	83.3%
2011	69,597	59,933	86.1%
2012	71,594	62.002	86.6%
2013	60,646	52,358	86.3%
2014	62,253	55,074	88.5%
2015	56,375	50,418	89.4%
2016	78,182	70,831	90.6%

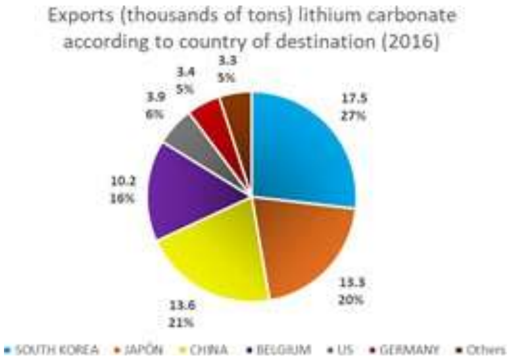

Fig. 5 Exports of Chilean lithium carbonate according to destination country (2016)

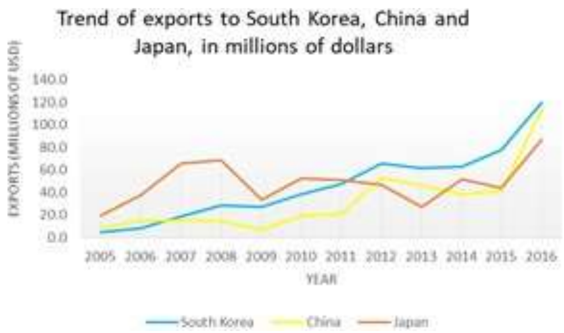

Fig. 6 Exports to South Korea, China and Japan

Fig. 7 Exports in thousands of USD according to lithium products (2012-2016)

Table 7. Evolution of FOB value lithium carbonate (2005-2016).

Year	Exports (ton)	Exports (thousands of usd)	Fob value (usd/ton)
2005	41831.54	90371.2	2160.4
2006	38680.50	120975.8	3127.6
2007	41125.26	187399.5	4556.8
2008	42585.72	223364.1	5245.0
2009	22443.20	114801.5	5115.2
2010	40895.76	174315.5	4262.4
2011	48247.84	204160.6	4231.5
2012	55899.29	247019.6	4419.0
2013	47593.94	225917.1	4746.8
2014	49467.30	228634.1	4621.9
2015	49611.18	245128.8	4941.0
2016	65163.17	457223.9	7016.6

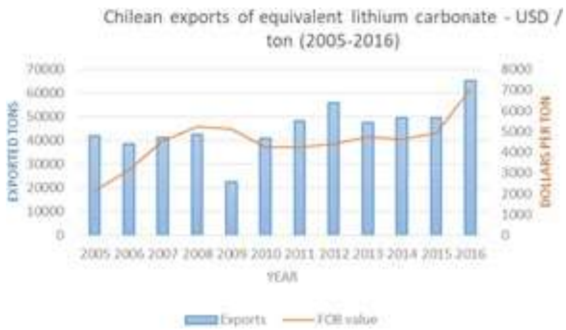

Fig. 8 Exports of lithium carbonate v/s FOB value

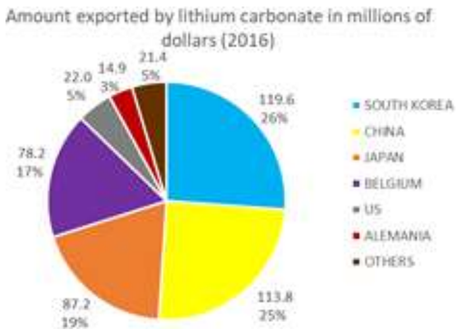

Fig. 9 Distribution by total amount of lithium carbonate exported by country of destination (2016)

Table 8. Estimated sales price per ton exported of lithium carbonate to each country in 2016.

	Tons of lithium carbonate	Usd millions	Fob lithium carbonate price (usd / ton)
SOUTH KOREA	17,476.2	119.6	6844.3
CHINA	13,610.4	113.8	8359.2
JAPAN	13,303.4	87.2	6552.5
BELGIUM	10,192.4	78.2	7676.5
U.S	3,916.3	22.0	5629.1
GERMANY	3,381.5	14.9	4421.0

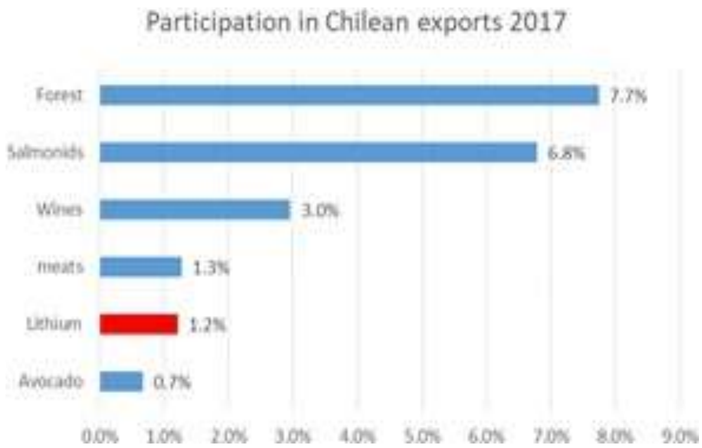

Fig. 10 Participation of lithium in exports from Chile 2017

These variables are as follows:

language	Common language between countries i, j;
EU	Countries that make up the European Union. Those present in this work are: Germany, Belgium, Spain and Italy.
naphtha	Countries belonging to the North American free trade agreement: USA, Canada and Mexico.
Argentina	Commercial exchange between Argentina and Chile.
free_com	Countries with which Chile has free trade agreements and that do not belong to any of the above categories: China, South Korea and Thailand.
t1	Temporal variable that represents the years 2005-2006.
t2	Temporal variable that represents the years 2007-2008.
t3	Temporal variable that represents the year 2009 (economic crisis).
t4	Temporal variable that represents the year 2010.
t5	Temporal variable that represents the years 2011-2012.
t6	Temporal variable that represents the years 2013-2014.
t7	Temporal variable that represents the years 2015-2016.

Table 9. Dynamic panel data results.

Variable	Dynamic panel data
Ln (Exp-1)	0.42 *** (0.08)
Ln (Exp-2)	0.22 ** (0.07)
Ln (export GDP)	-1.56 ** (0.59)
Ln (distance)	2.02 *** (0.56)
Ln (import container price)	0.69 ** (0.21)
Ln (importer change)	0.57 * (0.28)
Ln (high technology export)	1.27 *** (0.27)
2011-2012	0.61 *** (0.10)
2015-2016	0.49 *** (0.12)
Constant	-39.64 *** (6.82)
Number of observations	138

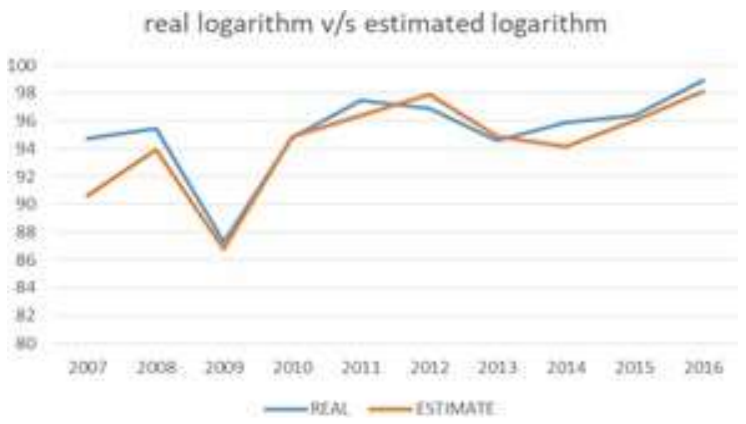

Fig. 11 Real exports, under natural logarithm v/s model and stimulated, under natural logarithm.

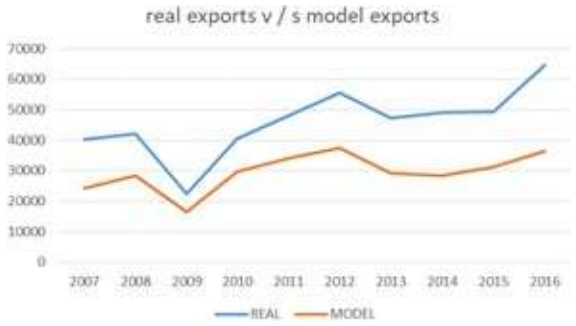

Fig. 12 Real exports v/s model exports

4. Conclusions

To model the exporter behavior, conform to a database with variables that could be significant in trade between the two countries; the correlation between variables is checked; multicollinearity and heterodasticity. After checking the database was carried out to estimate data by static panel fixed effect and random, then by test Hausman check which one is the most suitable. Then it was carried out to estimate dynamic panel data with two delays. Finally, the efficiency of the model is verified, comparing the real behavior with that estimated by the equation. As for the empirical results, it can be concluded:

- Variables not significant: GDP importer selling price of one ton of lithium carbonate price per container exported from SDE Chile, the actual change in the exporting country, the index of perception of corruption in both countries (exporter, importer), the Democracy index of the countries under study.
- Significant variables: Export of the previous year, export of two years ago, GDP of the exporter, distance between countries, price for importing container according to the country, the real exchange rate of the importer and the export of high technologies.

The GDP of the exporter has a negative coefficient, which, together with the positive coefficient of the distance between countries, makes that theoretically proposed by the gravitational model is not fulfilled because the higher the Chilean GDP, the less lithium carbonate it is exported and the greater the distance the importing country is, the more lithium carbonate exports are made . It is not the first time that this behavior has been observed in Latin America, for example, in the study carried out by Ovando, Canales and Munguía (2017), Colombia and exhibits similar behavior, importing more from countries with greater geographical distance.

Being the distance and cost coefficient for importing positive and significant containers , it is appreciated that buyers of lithium carbonate are willing to pay for the transportation and logistics needed to obtain this good. This is due to the fact that lithium carbonate is a manufacturing input and the costs of transport and import of lithium carbonate do not influence the volume that is imported proving that, in their formulation and evaluation of projects, importers consider a lot it is more profitable to acquire this good, assuming all transportation costs, rather than looking for a substitute with lower transportation costs. It should be remembered that the main lithium exporters are countries that generate manufacturing with high volumes and / or technology such as South Korea, Japan and China.

The coefficient of high-tech exports is presented as positive, so it is concluded that, the greater the export of goods with high technology, the greater the exports of lithium carbonate. Theoretically it is correct, since the exports of industrial products are fundamental for the economic growth of the countries (Herzer and Nowak-Lehmann, 2006). In addition, the positive nature of this coefficient makes it interesting to study the possibility of adding value to lithium carbonate.

The fact that the corruption index variables, together with the democracy index do not present significance in the model, should not be a reason to infer that Chile's political stability does not affect exports since, these variables do not measure stability The country's economic stability and its logistic stability, only measures aspects of institutional quality. For example, China has a precept of medium-high corruption, however, since 2014 it has been leading the Lloyd's List ranking of the 100 ports that mobilize more containers worldwide. Given this, it is recommended for future research to include a logistics indicator within the estimation variables, although for Latin American studies this indicator is scarce and is presented discontinuously.

Finally, the significance of the export years shows the recovery effect of lithium carbonate after a crisis. Presenting a recovery of the economic crisis of 2009 during the years 2010, 2011 and 2012, to repeat the effect in the years 2015 and 2016, after the global recession of the year 2014.

The time taken to carry out this investigation has not made it possible to carry out a method to handle the zero observations within the sample. It is recommended that another study be carried out where some of the strategies mentioned during this work are applied in order to mitigate their impact and obtain more precise estimates.

Acknowledgemet

Nill

Funding

No funding was received to carry out this study.

References

1. National Academy of Exact Sciences (ANCEFN). (2017). Lithium in ceramics, enamels, cements and similar materials. Lithium: A strategic natural resource. 1. 154-166.
2. lbemarle. (s/f). Albemarle logo. Recovered from http://www.albemarlelitio.cl/Albemarle. (s/f). The steps of Albemarle in Chile. Recovered from http://www.albemarlelitio.cl
3. Angulo, A., Mtimet, N., Dehibi, B., Atwi, M., Ben Youssef, O., Gil, J. and Sai, M. (2011). A revisited gravity equation in trade flow analysis: an application to the case of Tunisian olive oil exports. Regional Investigations 21. 225-239.

4. World Bank. (2018).World economic prospects, Latin America and the Caribbean Is the tide changing? Recovered from http://pubdocs.worldbank.org
5. Biessen, G., Is the impact of central planning on the level of foreign trade really negative? Journal of Comparative Economics. 15 (1). 22-44.
6. Bustamante, S., Campusano, S., Muñoz, F., Ortega, V., Santoro, E. (2012). Lithium. Production, demand and price.
7. Brada, J. and Méndez, A. (1985). Economic Integration among Developed, Developing and Centrally Planned Economies: A Comparative Analysis. The Review of Economics and Statistics. 67 (4). 549-556.
8. British Geological Survey (2016). Lithium Profile. Recovered from https://www.bgs.ac.uk/Cameán, I. (2011). Preparation of graphic materials: application as anodes in ion-lithium batteries. (Thesis to qualify for the degree of doctor, University of Oviedo). Recovered from: http://digital.csic.es
9. Cameán, I. (2016). Carbon nanomaterials: application in lithium-ion batteries. Spanish Coal Group Newsletter. 41.15-18. Carrascoso,M. (2014). Heat pump based on lithium bromide and water. Recovered from: http://www.dicat.csic.es
10. Chitue-de-Assunção - Nascimento, J., Lafargue - Pérez, F., Barrera - Vaillan, N., Díaz - Velázquez, M. and Rodríguez - Martínez, C. (2013).
11. Characterization of a bio-oil of Jatropha curcas L vegetable oil and lithium soap.Mechanical Engineering. 16(2).171-177. Codelco (2017). Annual Report 2016 Resources and Mineral Reserves.
12. National Lithium Commission. (2014). Lithium: A source of energy, an opportunity for Chile. Final report. Recovered from www.biblioteca.sernageomin.cl
13. Chilean Copper Commission (COCHILCO). (2009). Background for a public policy on strategic minerals: Lithium. Recovered from http://www.chiperchile.cl
14. Chilean Copper Commission (COCHILCO). (2013). International lithium market. Recovered from https://www.cochilco.cl.
15. Chilean Copper Commission (COCHILCO). (2014). The exploitation of lithium in Chile in the context of the international market. Recovered from http://www.cochilco.cl/
16. Chilean Copper Commission (COCHILCO). (2017). Imarket international lithium and its potential in Chile. Recovered from http://www.cochilco.cl
17. Special investigative commission of the Chamber of Deputies. (2016). Nform of the special research commission of “the participation of every company or public organism in the exploration, processing, exploitation, export and transport of lithium, as well as the characteristics of the contract signed between corfo and sqm for the exploitation of metal said.” Recovered from www.cacamara.com. cl
18. Contrading. (2018). Detection Of Multicolineality and Solutions. Retrieved on January 8, 2019, from http://www. cotradingclub.com
19. Corporation for the Promotion of Production (CORFO) (2016), Presentation Research Commission Lithium. Work presented in the Chamber of Deputies. Recovered from www.camara.cl
20. CORFO. (2018). CORFO increases Albemarle’s lithium quota. Recovered from https://www.corfo.cl/
21. CORFO. (2018). Improvement and Modernization Corfo Contracts with Albemarle and SQM. Recovered from https:// slideplayer.es
22. CORFO. (2018). OUTLOOK IN THE LITHIUM INDUSTRY. Recovered from https://www.camara.cl
23. De Arce, R. and Mahía, R. (2009). BASIC CONCEPTS ON HETEROCEDASTICITY IN THE BASIC MODEL OF LINEAR REGRESSION TREATMENT WITH E-VIEWS. Recovered from http://www.uam.es
24. Department of Electronics (UTFSM) (2010), Battery Technology, Federico Santa María Technical University. Recovered from http: // www.electronica.usm.cl
25. Desormeaux, D. (April, 2018), Lithium: Market and Regulation in Chile , Work presented at EXPOMIN 2018. SIGNUM BOX. Recovered from http: // www.congreso. expomin.cl
26. Diallo, A., Yinzhonghua, Morris, J., and Kolin, S. (2017). Panel Data Analysis of African’s Trade: The Gravity Model Approach. International Knowledge Sharing Platform. 7 (7). 73-85.
27. DIRECON-PROCHILE (2018), Yearbook of Chilean exports 2018. Retrieved from http: // www.direcon.cl
28. Eichengreen, B. and Irwin, D., (1995). Trade blocs, currency blocs and the reorientation of world trade in the 1930s . Journal of International Economics. 38 . 1-24.
29. Eichengreen, B. and Irwin, D., (1996). The role of history in bilateral flows. NBER Working Papers Series. 5565
30. El-Sayed, M. (September, 2012). A Gravity Model Analysis of Egypt’s Trade and Some Economic Blocks. Presented at: International Conference on Applied Life Sciences, International Society for Applied Life Sciences (ISALS), Turkey, Retrieved from: https://cdn.intechopen.com/
31. Flores, H., Valdez, S. and Orce, A. (2017). Recovery of Mg (OH) 2 from brines. Presented at: IX International Conference on the Use of Mineral Resources. Higher Metallurgical Mining Institute of Moa. Cuba. Recovered from: http://cinarem.ismm.edu.cu/
32. Frankel, J. and Fellow, S. (1997). REGIONAL TRADING BLOCS . U.S. Harvard University
33. Fuenzalida-O’Shee, D .; Valenzuela-Klagges, B .; Corvalán-Quiroz, A. (2018). Commercial facilitation and its effects on Chilean bilateral trade from 2006 to 2014. CEPAL Magazine. (124). 173-191.
34. Gajardo, A. (2014), Lithium potential in salt flats in northern Chile. SERNAGEOMIN. Recovered from http: // www.sernageomin.cl
35. Garret, D. (2004), Handbook of Lithium and Natural Calcium Chloride. Britain. Elsevier
36. González, A. (2000). Mineral richness of Chile worldwide . Santiago.
37. Havrylyshyn, O. and Pritchett, L. (1991). European Trade Patterns After the Transition. Country Economics Department. The World Bank
38. Herzer, D. and Nowak-Lehnmann, F. (2006) What does export diversification do for growth? An econometric analysis. Applied Economics. 38 (15), 1825-1838, DOI: 10.1080 / 00036840500426983
39. Iglesias, R., Lago, A., Nogueiras, A., Martínez-Peñalver, C., Marcos, J., Quintans, C., Moure, MJ, and Valdés MD (2012). Modeling and Simulation of a Multicell Commercial Lithium Ion Battery. University of Vigo.
40. Johnston, L., Morgan, S., Wang, Y. (2014). The Gravity of China’s African Export Promise. The World Economy, 2014, Forthcoming.
41. Jordaan, A. and Hinaunye, E. (2011). IDENTIFYING SOUTH AFRICA’S WOOD EXPORTS POTENTIAL USING A GRAVITY MODEL. 2010 International Conference on E-business, Management and Economics. 3. 159-164.
42. Kepaptsoglou, K., Karlaftis, M. and Tsamboulas, D. (2010). The Gravity Model Specification for Modeling International Trade Flows and Free Trade Agreement Effects: A 10-Year Review of Empirical Studies. The Open Economics Journal. (3). 1-13.

43. Kumar, A. (2016). Selecting multipurpose fats: complex lithium or calcium sulphonate ? Recovered from: http:// noria.mx
44. Lombardi, P., Andrea Dal Bianco, A., Freda, R., Caracciolo, F. and Cembalo, L. (2016). Development and trade competitiveness of the European wine sector: A gra vity analysis of intra-EU flows. Wine Economics and Policy. 5 (1). 50-59
45. Macquarie Research. (2016). Global Lithium Report. Recovered from: http://www.newagemetals.com
46. Minetti, J. (2005). The climate of northeastern Argentina. Argentina: Magna.
47. Ministry of Economy and Public Finance. (2011). Mining Complex: Lithium. Recovered from https://docplayer.es
48. Ministry of Mining (2016). General Framework of Lithium and the new National Policy of Lithium and Governance of Salaries. Recovered from https://www.camara.cl
49. Ministry of Public Works. (2004). Salar de Atacama Basins. Recovered from http://portal.mma.gob.cl
50. Huntsman. R. (2005). Hausman test. Recovered from https://www.ugr.es
51. Osses, L., (May, 2018). Lithium technologies and the value chain . Work presented in the framework of “Thursday miners”. Institute of Mining Engineers of Chile. Santiago.
52. Ovando, W., Canales, R., Munguía, G. (2017). Interregional trade in manufactured goods in the Pacific Alliance countries from Linder’s Theory. Challenges, 29 (2). 169-197.
53. doi: http://dx.doi.org/10.12804/revistas.urosario.edu.co/desafios/a.4876
54. Polanco, E. (2005), History of SOQUIMICH, a review. Recovered from www.sitiohistorico.sernageomin.cl
55. Primo, E. (1996). Basic and applied organic chemistry. Spain: I reversed.
56. Resource World Magazine. (2018). Lithium Triangle [Image]. Recovered from http://resourceworld.com
57. ELECTRICITY Magazine. (2018). Approved increase of quota of lithium extraction of SQM. Retrieved on July 03, 2018 from http://www.revistaei.cl/2018/03/09/
58. Rockwood Litio Ltda. (August, 2014). Operations and projects of Rockwood Litio Ltda. Recovered from http: // www.sonami.cl
59. Rodriguez, G. and Dávalos, J. (2017). The Trans-Pacific Partnership Agreement (TPP) Trade Potential for Peru, a Gravity Model Approach. GECONTEC: International Journal of Knowledge and Technology Management. 5 (2). 93-107.
60. Romano, F., Balderrama, F. (2013). Solvent extraction of boron from evaporated brines from the Salar de Uyuni with 2-ethyl-1-hexanol and 2-ethyl-1,3-hexanediol. UTO Metallurgical Magazine. (3. 4). 13-17 Recovered from www.revistasbolivianas.org.bo
61. Sánchez, R. (2011). Formulation and processing of oleogels for the development of new biodegradable lubricating greases. (Memory to qualify for the degree of doctor, University of Huelva). Recovered from: rabida.uhu.es
62. Santos, J. and Tenreyro, S. (2006). The log of gravity. Review of Economics and Statistics. 88 (4). 641-658.
63. Sawyer, J. (1967). The Canadian Journal of Economics and Political Science / Revue Canadienne D’Economique Et De Science Politique, 33 (4). 633-634.
64. Serrano, R. and Pinilla, V. (2010). AGRICULTURAL AND FOOD TRADE IN EUROPEAN UNION COUNTRIES, 1963-2000: A GRAVITY EQUATION APPROACH. Spanish Association of Economic History.
65. Signum Box (2015). What to expect from the Chilean lithium industry after the National Commission’s advancement plan? Recovered from: http://lwww.indmin.com
66. SQM (s / f). SQM logo. [Image]. Recovered from https://www.sqm.com
67. SQM (s / f). Our history. Retrieved on December 12, 2018, from https://www.sqm.com
68. Tansey, M. and Touray, A. (2010). The Gravity Model Of Trade Applied To Africa. International Business & Economics Research Journal. 9 (3). 127-130.
69. Tay, C. (2013). An econometric model on bilateral trade in education using an augmented gravity model. Journal of Industrial Engineering and Management. 7 (2). 402-412.
70. The Economist (2017). Democracy Index 2017. Recovered from: https://pages.eiu.com
71. Transparency International (2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016). CORRUPTION PERCEPTIONS INDEX. Recovered from https://www.transparency.org
72. Ulloa, C. (2017). TRADE BETWEEN THE COUNTRIES OF THE PACIFIC ALLIANCE. AN ANALYSIS FROM THE GRAVITATIONAL MODEL AND BILATERAL EXCHANGE. TEAC . (twenty). 11-19.
73. USGS (2017). MCS Lithium 2017. Retrieved on April 27, 2018 from https://minerals.usgs.gov
74. USGS (2018). MCS Lithium 201 8. Retrieved on November 5, 2018 from https://minerals.usgs.gov
75. Valenzuela-Klagges, B. (2011). COMMERCE AND INSTITUTIONAL QUALITY IN THE ECONOMIC GROWTH OF THE SOUTH AMERICAN CONE: ISSUES AND CHALLENGES. Pilquen Magazine - Social Sciences Section, (14), 1-8.
76. Wang, Z., & Winters, L. (1992). The Trading Potential of Eastern Europe. Journal of Economic Integration, 7 (2), 113-136.
77. Winters, L. (1992). The Trading Potential of Eastern Europe. Journal of Economic Integration, 7 (2), 113-136.
78. Zambra, M. (June, 2016). Lithium and its interest for nuclear energy. Presented in seminar: The meaning of lithium for the development of the country. San Sebastian University. Santiago.