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The impact of commodity price shocks among regional economies of a developing country*

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Volatile commodity prices have become commonplace in the world economy. Although is widely accepted that commodity-rich countries are affected by this phenomenon, information about how commodity price shocks impacts their regional economies is scarce. This work analyses how shocks in copper prices impact the economies of the major copper-producing regions in a developing country, such as Chile. To achieve this goal, a two-step method is implemented. First, we estimate long-term copper prices using the Wets and Rios approach (2015) and these estimates are then contrasted with those forecast by the Chilean public advisory committee. Second, a general equilibrium model is implemented to simulate the effects of both expansive and restrictive copper price cycles within major producing regions in Chile. Our results show that the proposed approach yields more homogeneous price projections than those made by the Chilean Government, which, in turn, are very close to variations in response to negative shocks. The price simulations confirm that price cycles affect the savings of government and business, which directly dampens regional production, mainly via investment, capital mobilisation and diversification of production. Because of this, fiscal revenues generated by copper sales act as a trade cycle term multiplier in regional economies. Overall, within copper-producing regions, we suggest implementing long-term policies to improve profit distribution efficiency.

Key words: Chile, copper, commodities, prices, regional economies.

1. Introduction

Mining projects depend on highly uncertain variables, such as resource prices, ore grades, discoveries of new reserves, mine development and technological advances. Variations in these can be transmitted to the rest of the economy through a number of pathways (Lagos 1997). Of these, naturally, commodity price volatility particularly affects the economies of producing countries (Frankel and Rose 2010). The general focus of this study is how shocks in commodity prices impact the economy of the country in which it is produced. More precisely, and bearing in mind that Chile is the largest copper producer in the world (Chilean Copper Commission 2016 - hereafter COCHILCO),

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the study examines the case of how fluctuations in copper prices affect the economies of the major Chilean copper-producing regions. Given the complexity of these interrelations, we propose a two-stage method that deals with this particularity at the national and regional levels. This method takes into account diverse market mechanisms which determine the decisions of economic agents and the effectiveness of policies. First, we estimate long-term copper prices using the Wets and Rios approach (2015) and then, in order to check the robustness, we contrast these estimates with the forecasts of the Chilean public advisory committee. Second, a general equilibrium model is implemented to simulate the effects of both an expansive and a restrictive copper price cycle among major Chilean copper-producing regions. This model, as an evaluation instrument, addresses many limitations by representing local economies in a more realistic manner: it incorporates market and price mechanisms in the assignment of resources. In summary, our approach innovates by incorporating long-term trends and short-term volatility to control for asymmetric responses to positive and negative shocks in copper prices.

The economics of non-renewable resources have been attracting increasing academic interest in the field of resource economics. One avenue for this research has been focusing on forecasting and modelling commodity prices (e.g. Irvin *et al.* 2009), while another, more related to the present work, analyses how fluctuations in commodity prices affect economic variables and policies (e.g. Rolfe *et al.* 2011). While shocks to oil prices have been repeatedly investigated in the literature, fewer studies exist on the effects of shocks from prices in other commodities. A number of papers, however, do analyse the general impact of commodity price shocks. For example, Böwer *et al.* (2007) study the impact of commodity price increases on monetary and fiscal policies in Western and Central Africa during 1999-2005. They found that these rallies positively affected growth in oil-exporting countries, while non-oil-producing countries experienced lower growth rates, even though they benefitted from the overall increase in commodity prices. On the other hand, Chen *et al.* (2010) studied the relationship between real exchange rates and commodity prices in resource-rich exporting countries. They found that real exchange rates in commodity exporting countries are higher in periods where commodity prices are high. Along the same line, Akram-Lodhi (2007) argued that lower real interest rates and weaker dollar exchange rates lead to higher commodity prices. While these studies analyse the general impact of commodity price shocks, they do not offer insights into the sectorial interrelationships of the mining sector, let alone the effects of copper price fluctuations. Further, they do not provide information about how copper price volatility impacts local or regional economies, and do not consider these changes over time.

In responding to these gaps in the literature, our approach analysed direct and indirect economic effects of copper mining among regional producing sectors. The remainder of the paper is organised as follows: Section 2 describes the copper price formation mechanism among international markets; Section 3 reviews the importance of copper mining in Chile; Sections 4 and 5 show the estimation strategy; and Section 6 presents the results and discussions. The last section concludes.

2. The formation of copper prices

Following Radetzki *et al.* (2008), when countries are highly dependent on natural resources, their ability to grow in the long term may be affected. According to these authors, the main driving factor behind this situation is price volatility, which affects commodity prices. As depicted in Figure 1, international copper prices have experienced a downward trend over time with different trend changes across different periods. From 1935 until the 1970s, there were strong price fluctuations, which were mainly because of the Great Depression and the oil crisis. In the early 1970s, prices rose sharply and then begin to fall steadily, reaching historic lows in the early 2000s. All these variations show changes in the average prices of each cycle and therefore influence the long-term price.

There are a limited number of studies that have addressed the effect of copper price shocks on a developing country, such as Chile. Calvo and Mendoza (1998) estimate a VAR model with data from 1986 to 1997 and find that the terms of trade, defined at the ratio of the copper price and the oil price, Granger, causes the Chilean activity. Medina and Soto (2007) used

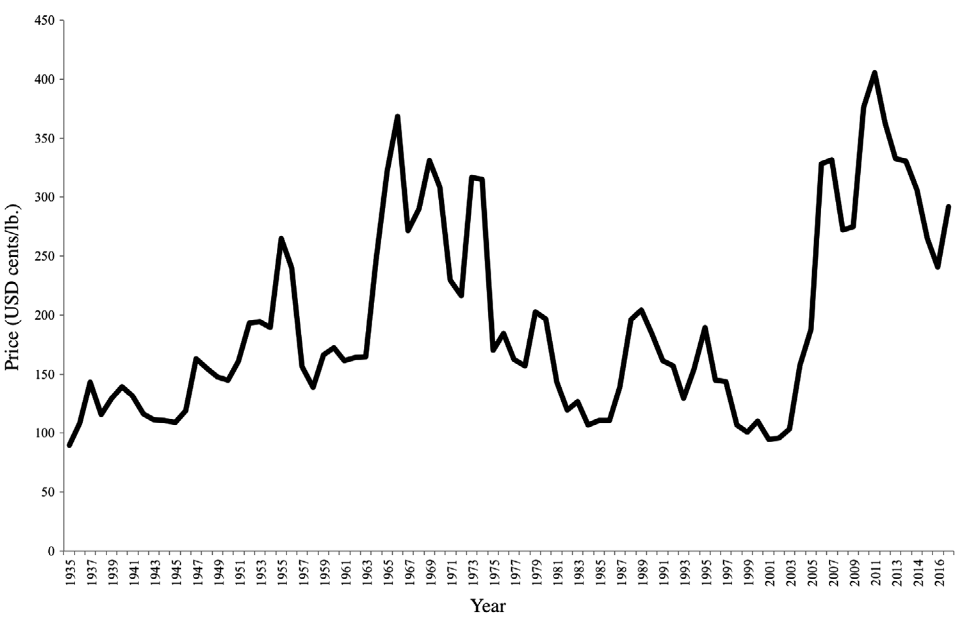

Figure 1 Evolution of the international real price of copper. COCHILCO (2017).

a dynamic stochastic general equilibrium model (DSGE) to compare the effects of transitory copper price shocks under different fiscal rules. The results show that if the fiscal policy is conducted using a structural balance fiscal rule, such that the Chilean Government saves most of the extra revenues from the higher copper price, then a copper price shock of 10 per cent would increase output only by 0.05% and there would be a slight decrease in inflation. This last effect occurs due to a real appreciation of the exchange rate that compensates a slight increase in domestic goods inflation. In contrast, when fiscal policy is highly expansive, the same copper price increase implies an output expansion of up to 0.7%, an increase in inflation, and a real exchange rate appreciation of 0.2%. Medina (2010) applied a four-dimensional VAR model where shocks are identified by a Cholesky decomposition. The author finds that an international commodity price shock affects the Chilean GDP positively and significantly so. De Gregorio and Labbe (2011) estimate a vector error correction model (VECM) with data from 1977 to 2010 and argue that the Chilean economy has become more resilient to copper prices shocks, partly because the real exchange rate has acted as a shock absorber. The study by Wets and Rios (2015) most resembles our analysis. They proposed an approach that analyses how a copper price shock returns to its long-term path, thereby providing information about its duration and size over time. Their approach includes asymmetric responses to positive and negative shocks on long-term copper prices.

In Chile, resource sectors make a significant contribution to the national and regional economies. However, the information about how they impact regional economies is scarce. In this sense, our study fills a void in the current literature by analysing how shocks in copper prices impact economic variables among major Chilean copper-producing regions.

3. The Chilean copper mining sector

Copper mining is the main productive sector in Chile. Between 2006 and 2016, copper exports reached 54 per cent of total Chilean exports. At the domestic level, foreign investment in the mining sector was, on average, 33 per cent of overall investment, and the annual fiscal transfers from copper mining fluctuated between US$3.5 and US$8.4 billion (COCHILCO 2016). Table 1 presents contributions to added value on exports, direct foreign investment and share in wages of Chilean copper mining.

The mining cycles have had an enormous impact on the Chilean industry changes. They are geographically dispersed and capital-intensive (Badia-Miró and Yañez 2015). At the regional level, Chilean copper production is conducted primarily in the Regions of Tarapaca (Region I), Antofagasta (Region II), Atacama (Region III), Coquimbo (Region IV), Valparaiso (Region V) and Libertador General Bernardo O'Higgins (Region VI). Among them, the Antofagasta is the leading copper-producing region,

Table 1 The impact of copper mining activity on the Chilean economy

	2006	2016
Total exports (billions of nominal US$)	21	78
Copper exports (billions of nominal US$)	8	42
Share in exports	38%	54%
Mining investment (billions of nominal US$)	2.9	11.3
Share in total investment	10%	17%
Net public revenue (billions of nominal US$)	17	50
Public revenue from Copper (billions of nominal US$)	3.5	8.4
Share in public revenues	21%	17%

Source: COCHILCO Annual Reports 2006 and 2016.

accounting for between 53 per cent and 65 per cent of national production since 2004 (National Geology and Mining Service 2017 – hereafter SERNAGEOMIN).

Twenty companies conduct large-scale operations. Among them, three types can be found: state-owned, mixed and private. There is a single state-owned firm, the National Copper Corporation (hereafter CODELCO). By 2016, mine production from large-scale companies and CODELCO was about 6.5 million metric tonnes (Mt) or 95.2 per cent of the total.

For their part, the state-private joint ventures (mixed) are made up of: i) Sociedad Contractual Minera El Abra; ii) Anglo American Sur S.A.; (iii) Compañía Minera Teck Carmen de Andacollo; and (iv) Compañía Minera Teck Quebrada Blanca S.A.

With respect to private mining, the major owner is BHP Billiton, which accounts for 16.4 per cent of the domestic copper production. Next in importance are Anglo American (9.4 per cent), the Luksic group (8.1 per cent), the Rio Tinto group (6.2 per cent), Glencore (4.9 per cent) and the Mitsubishi group (3.6 per cent).

As well, 22 private companies represent medium-scale operations accounting for 5 per cent to 6 per cent of annual copper production, while small-scale operations account for about 2 per cent of the national total (COCHILCO 2016). Table 2 shows the regional production of copper according the type of copper traded.

In the last 20 years, copper production from private companies increased relative to public companies. The high share of copper concentrate is mainly due to the dominance of private mining, which produces mostly copper concentrate instead of refined copper. The state-owned company CODELCO produces mostly refined copper, which corresponds to SX-EW cathodes. However, during the last 5 years CODELCO has followed the trend of private companies with an increase in the relative importance of concentrate over refined copper. This helps to explain the large fall in the percentage of refined copper from 2009 onwards. A fundamental problem, then, is that the mining companies with the highest production are those that proportionally

Table 2 Copper production by region and product type (expressed in tonnes)

	2010	2011	2012	2013	2014	2015	2016
MINERAL COPPER (Concentrates)							
Tarapaca (Region I)	465.2	417.3	245.3	416.1	445.4	433.1	501.8
Antofagasta (Region II)	1,287.4	1,127.4	1,310.8	1,454.2	1,559.1	1,642.7	1,568.2
Atacama (Region III)	314	349.5	326.2	377.4	356.3	405.1	430.9
Coquimbo (Region IV)	430.2	459.1	449.5	447.6	437.4	404.5	392.2
Valparaiso (Region V)	236.1	291	315.8	302.6	279.3	272.1	253.3
LBO (Region VI)	422.8	415	435.6	467.1	471.3	469.5	474.9
COPPER BARS (SX-EW Types)							
Tarapaca (Region I)	229.7	209.1	185.8	172.6	162.6	145.4	113.7
Antofagasta (Region II)	1,658.3	1,611.8	1,639	1,569.9	1,491.6	1,454.9	1,361.8
Atacama (Region III)	119.9	119.2	118.1	116.1	115.8	104.5	116.4
Coquimbo (Region IV)	14.8	19.7	22.7	20.6	15.5	12.6	10.9
Valparaiso (Region V)	21.3	25.1	21	22.7	18.5	18.6	18.4
LBO (Region VI)	2	1.6	1.2	1.3	1.8	1.7	1.1
Total							
Tarapaca (Region I)	694.9	626.4	431.1	588.7	698	578.5	615.4
Antofagasta (Region II)	2,945.7	2,739.2	2,948.8	3,016.1	3,050.7	3,097.6	2,930
Atacama (Region III)	433.9	468.7	443.3	493.5	472	509.6	547.4
Coquimbo (Region IV)	445	478.7	472.2	468.2	452.9	417.1	403.1
Valparaiso (Region V)	257.4	316.1	336.9	325.3	297.8	290.7	271.6
LBO (Region VI)	424.8	416.6	436.8	468.4	473.1	471.2	476

least elaborate their product. This affects the structure of the productive chains related with the copper industries (Spilimbergo 2002).

4. Methodology

We study how copper price shocks affect the economies of major Chilean copper-producing regions. The regions considered are Tarapaca, Antofagasta, Atacama, Coquimbo, Valparaiso and Libertador General Bernardo O'Higgins. Given the complexity of these interrelations, we propose a two-stage method that considers market mechanisms and price dynamics.

The first step is to project long-term copper prices and to contrast these estimates with those forecasted by the Chilean public advisory committee. The Government price forecasts are used as a reference for the copper price compensation fund and serves as an estimate for both the structural balance of the public sector and the state budget. As a result, the act of projecting prices that are very resilient to international conditions has significant economic implications on the regional economies. This comparison allows the analysis of the direct and indirect effects of mining on other productive sectors and other economic aggregates.

The second step focuses on measuring the effects of variations in copper price cycles on regional economies. A general equilibrium model to simulate the effects of expansive and restrictive copper price cycles among major Chilean copper-producing regions is implemented. The expansive cycle simulation consists of a 10 per cent increase in long-term copper prices; while the restrictive cycle simulates the effects of a 10 per cent decrease. The model specifications include labour and income-group differentiation, trade partners, and specified productive factors (Beghin *et al.* 1996; O′Ryan *et al.* 2003).

First, we forecast long-term copper prices by using the Wets and Rios approach (2015). This model presents a reversion to an unobservable long-term marginal cost that follows a trend together with random fluctuations in both the level and time of this trend (1). The specification is as follows:

$$y_i^t = y_i^{t_0} \exp\left[\left(u_i + \frac{1}{2\sum_{j=1}^{J} b_{ij}^2}\right)(t - t_0) + \left(\sum_{j=1}^{J} b_{ij}\left(w_j^t - w_j^{t_0}\right)\right)(t - t_0)\right] + v_i(1 - e^{-u_i t}) \tag{1}$$

where y^t is the future value of index i (given); μ_i and b_{ij} are constants that need to be estimated; w_j, j = 1,..., J are independent (standard) wiener processes; υ_i is an index to which y_i^t reverts in the long term; and μ_i is the ‘speed’ at which y_i^t reverts toυ_i.

With respect to Chilean forecasts of copper prices, an advisory committee has been created with the specific task of guaranteeing the independence of the structural balance process and with assessing medium-term projections of the public structural budget. Prices published by that group are estimated by a consulting round with a panel of 16 experts, each of whom are asked for average price estimates for the next 10 years (excluding the lowest and highest estimates). In this study, variations in long-term prices are simulated by calculating average prices over a 20-year horizon for each year in question; that is, for 2017, the average variation until 2037 is calculated, for 2018, until 2038 and so on.

Second, we implement a general equilibrium model framework which contains the following indexes: productive sectors or activities (i, j); types of work, or occupational categories (l); household income groups, expressed in quintiles (h); public spending categories (g); final demand spending categories (f); trade partners (r); and different types of pollutants (p). The production structure is modelled by CES/CET nested functions (i.e. constant substitution elasticity and constant transformation elasticity). If constant returns to scale and minimised costs are assumed, each sector produces:

$$\min\ PKEL_i KEL_i + PND_i ND_i \tag{2}$$

$$s.t.\ XP_i = \left[\alpha_{KELi} KEL_i^{\sigma_i^p} + \alpha_{NDi} ND_i^{\sigma_i^p}\right]^{1/\sigma_i^p} \tag{3}$$

where *KEL* is a composite good of capital, energy and labour; *PKEL* is the price of *KEL*; *ND* is a composite good of no-energy intermediate inputs; *PND* is the price of *ND*; *XP* is total output; α is the share of input/factor use; and σ is the substitution elasticity. Households use their income for consumption and savings, which is modelled by an ELES utility function (extended linear expenditure system). This function also incorporates minimum subsistence consumption as independent from the level of income.

$$\max\ U = \sum_{i=1}^{n} \mu_i \ln(C_i - \theta_i) + \mu_s \ln\left(\frac{S}{CPI}\right), \quad (4)$$

$$\text{subject to} \sum_{i=1}^{n} PCi_i Ci_i + S = YD \text{ and} \quad (5)$$

$$\sum_{i=1}^{n} \mu_i + \mu_s = 1, \quad (6)$$

where U stands for consumer utility; C_i is the consumption of good i; θ_i is subsistence consumption; S, savings; CPI, the price of savings; and μ, the marginal propensity to consume each good or to save. Regarding public finances, there are different types of taxes and transfers. The following, all of which are direct, are defined in the model: labour tax (differentiated by occupational category), taxes on firms, and taxes on income (differentiated by quintile). Considering that the present paper seeks to analyse the impact of copper price variations on regional economies, the construction of a social accounting matrix (SAM) is proposed. This SAM includes only the copper-producing regions of Chile and will serve as the basis for adapting the previously described general equilibrium model to these regions. This regional SAM is an extension of the regional input-output matrix calculated by the Chilean Central Bank in 1996, which is the latest official version.

The regional SAM will also include the specific accounts that comprise the Chilean National Account System, published by the United Nations in 2003. It was constructed using previous methods developed by Riffo *et al.* (2006), Rojas (2009), and Mardones (2012). These methods mainly consist of the use of linear relationships between region-specific data and applying a multiplier accounting (MA) model to the constructed SAM, thus identifying absorption (linkages moving forward) and diffusion (linkages moving backwards) effects of each of the accounts involved. The particular methodology used in the construction of the social accounting matrix for copper-producing regions was the top-down method, as proposed by Thorbecke (2000), which consists of the construction of a SAM in two stages. In the first of these, the aggregate (or macro) SAM is constructed based mainly on data from the National Accounts. This matrix provides a general description of regional economies and presents the accounts that make up a SAM in aggregate form (accounts of goods and services, production, productive factors and institutional sectors, without distinguishing among the different productive sectors of the economy, the employment categories or household quintiles). This allows for the development of a set of sub-matrices, which detail all the relevant data for each region under study. The second stage disaggregates some of the accounts through secondary statistical sources, which gives the definitive regional SAM. For this work, the simulation was run for 1997, 2002, 2007, 2012, 2017, 2022, 2027, 2032 and 2037. Overall, this evaluation instrument solves many limitations by representing regional economies in a more realistic manner through the incorporation of market and price mechanisms in the assignment of resources.

5. Data

For price estimates, yearly series of international real copper prices (log scale) for 1935-2016 were used. These prices were obtained from the United States Geological Survey (1935-1998) and the Copper Chilean Commission (1999-2016). The CPI data from the United States are used to calculate real copper prices. For the simulation strategy, the CGE model incorporates the social accounting matrix (SAM) as the main source of domestic information. In short, the matrix for Chile was built based on the input-output matrix provided by the Chilean Central Bank (2016). That SAM has 73 sectors, 20 labour categories (10 rural, 10 urban), 10 groups of income (divided by deciles) and 28 trade regions. Secondary data from official surveys on economic, productive, labour, consumption and social variables for each region, as well as foreign and domestic trade information, were obtained from the Chilean Central Bank, Chilean National Account System, COCHILCO and SERNAGEOMIN.

6. Results and Discussion

6.1 Price forecasting and comparison

The Wets and Rios approach (2015) requires determining whether the series has a stable (stationary) trend. Briefly, if the hypothesis that the price series has a unit root is rejected, it is feasible to estimate a future price path on a trend. If, on the other hand, the unit root hypothesis is accepted, the best estimate of future prices is the last known value. To determine stationarity of the time series, the Elliott-Rothenberg-Stock test (1996) was conducted. Based on test results, the unit root hypothesis for the sample is rejected[1]. Consequently, it is possible to estimate future prices through a mean reversion procedure, as defined by the proposed approach. The prices projected by this approach and by the committee of experts were contrasted with a positive and negative variation of 10 per cent. The results for price elasticity suggest that an increase of 10 per cent in the short-term price

[1] All results from the unit root test are available upon request.

represents an increase of 1.27 per cent in the long-term price. On the other hand, price dynamics associated with a negative shock are far more pronounced. It begins with a 14.31 per cent decrease in the initial years followed by a 1.26 per cent decrease in price after 20 years, as seen in Figure 2. In both cases, one could infer that the effect of these shocks is not transitory. In other words, the trend of positive and negative prices does not return to an initial state, so the effect on regional economies is long term.

From a comparative perspective, when rates of return with respect to long-term price dynamics are quantified, rates at which prices rise and fall are relatively homogeneous, allowing for more stable forecasts of long-term time horizons (see Table 3).

With above results, the next step contrasts the previous estimates with the forecasts by the Chilean advisory committee, available through 2026. These latter values are presented in Table 3.

The comparison shows that the Wets and Rios approach (2015) reasonably predicts the prices projected by the panel of experts in a scenario of mainly negative transitory shock. Three main implications can be projected from this particular scenario (Table 4).

First, a fall in the international price of copper generates a depreciation of the local currency, which induces effects that offset these negative effects on mining production. For example, there may be positive effects on exporting productive sectors such as non-renewable, renewable and industrial sectors (Mardones 2012). These positive income effects imply a rise in the demand for production factors, including demand for inputs from the non-mining export sector (Riffo *et al*. 2006). As a result, one could expect synergistic effects along the mining supply chains with the rest of the economic sectors, particularly those that complement mining development (O´Ryan *et al.* 2008). Following Bravo-Ortega and De Gregorio (2006), these implications could generate the following scenarios: (i) that the mining industry has low forward linkages,

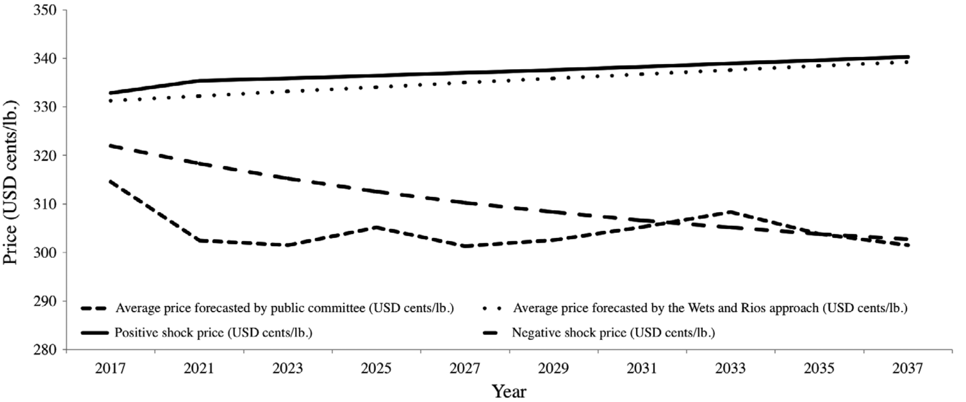

Figure 2 Long-run dynamic of average prices in response to 10% positive and negative shocks in 2016.

Table 3 Average long-term price and variations in response to a single price shock of 10%

Year	Average price (USD cents/lb.)	Price with a positive shock (USD cents/lb.)	Variation with a positive shock	Price with a negative shock (USD cents/lb.)	Variation with a negative shock
2017	330.27	334.53	1.27%	326.11	−1.26%
2018	331.26	332.85	0.48%	321.95	−2.81%
2019	332.22	335.38	0.94%	318.36	−4.17%
2020	333.16	335.88	0.81%	315.26	−5.37%
2021	334.08	336.43	0.70%	312.59	−6.43%
2022	334.98	337.01	0.60%	310.29	−7.37%
2023	335.87	337.64	0.52%	308.30	−8.21%
2024	336.74	338.27	0.45%	306.59	−8.95%
2025	337.59	338.92	0.39%	305.12	−9.62%
2026	338.44	339.60	0.34%	303.84	−10.22%
2027	339.27	340.28	0.30%	302.74	−10.77%
2028	340.09	340.97	0.26%	301.79	−11.26%
2029	340.90	341.67	0.23%	300.97	−11.71%
2030	341.71	342.40	0.20%	300.26	−12.13%
2031	342.50	343.10	0.17%	299.66	−12.51%
2032	343.28	343.81	0.15%	299.14	−12.86%
2033	344.06	344.53	0.14%	298.69	−13.19%
2034	344.83	345.25	0.12%	298.30	−13.49%
2035	345.59	345.96	0.11%	297.97	−13.78%
2036	346.35	346.69	0.10%	297.68	−14.05%
2037	347.10	347.41	0.09%	297.43	−14.31%

because the products do not serve as inputs for other areas of production; (ii) that the basic manufacture of metals has low backward linkages, because it uses relatively few domestic inputs; and (iii) that at the same time, the mining industry has low backward linkages, due to the fact that one of its main inputs, the basic metals industry, is not available in domestic production, and these products must be imported (Table 5).

Second, a downward price projection in copper could generate two situations: (i) a distributive effect, associated with an improvement in relative income of the lowest quintiles; and (ii) a tendency to produce more copper concentrate, traded under long-term contracts with less exposure to violent price variations. If one considers that the elaboration of refined copper cathodes is an important condition to promote productive chains (Spilimbergo 2002), the second situation is discouraging. If mining companies will prefer to produce concentrated copper without any type of promotion policy for copper refining, then the production of refined copper will decrease. Given this situation, studying the copper-manufacturing sector then becomes a primary task to understand the behaviour of the market and thus observes the best policies to enhance production chains.

The third scenario relates to the distribution of capital. As demonstrated by Ebert and La Menza (2015), Chile presents a large share of elementary labour with low skill levels. As a result, the contraction of a capital-intensive sector causes capital to be reallocated to other sectors with more intensive unskilled

Table 4 Copper price forecasting by Chilean advisory committee (expressed in USD cents/lb.)

Year/Expert	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Average price
2017	325	295	305	305	315	315	320	301	305	295	353	315	325	300	340	320	314.6
2018	320	254	275	285	299	284	314	313	304	270	357	306	324	275	320	340	302.5
2019	305	224	251	280	281	269	366	342	303	275	346	308	324	260	330	360	301.5
2020	292	234	236	295	279	273	372	348	301	285	327	309	323	300	350	360	305.2
2021	280	254	231	295	282	277	318	336	303	310	302	310	323	320	330	350	301.3
2022	269	285	272	287	290	281	270	296	304	315	289	311	323	340	360	350	302.6
2023	259	295	310	287	294	302	264	272	306	320	284	310	323	380	330	350	305.3
2024	250	315	346	287	291	313	245	260	308	325	280	311	323	380	350	350	308.3
2025	242	320	322	287	288	316	240	254	309	335	275	310	323	350	340	350	303.8
2026	242	320	298	287	285	318	247	254	311	340	270	310	323	330	340	350	301.5

Table 5 Price dynamics for simulations

Year	Long−term price increases	Short-term price decreases
2017	3.6%	−3.5%
2020	1.8%	−1.8%
2027	0.9%	−0.9%
2032	0.5%	−0.4%
2037	0.3%	−0.2%

labour use. In other words, while this scenario may promote an improvement of the income distribution, it is restrictive in terms of income level. This is mainly because the downturn in the copper sector is offset by an increase in other productive sectors, primarily those that are more intensive in unskilled labour. This deficit of high productive jobs that theoretically pay higher wages should motivate consideration of using some part of the offset resource revenue to invest in high skilled jobs at the same time as increasing investment in human capital. These authors claimed that investing revenue from exhaustible copper resources into long-term productive assets outside the mining sector could reduce the deficit while stimulating domestic demand, creating a more robust approach to economic growth. Under the current scenario, the importance of more accurate price projection mechanisms at both national and local levels becomes apparent.

6.1.1 The impact of the quality of copper exports

In Chile, the production of cathodes has been reduced between 2010 and 2016, while the production of concentrates has grown at a very high rate. In 2010, the cathodes had 39.4 per cent of total Chilean copper production, while in 2016, they represented 30.6 per cent. In the case of concentrate, and without substantial changes in copper production, it increased from 60.6 per cent to 69.4 per cent in the same period (COCHILCO 2016). As previously stated, this trend has different impacts on regional economies. In a context of a downward trend in copper prices (as reasonably predicted by the Wets and Rios approach (2015), this could affect intensively those regions specialised in low-grade copper (concentrated), due to the existence of premiums for exports of bars and the lower level of industrial development required to produce it (when compared with cathodes). Therefore, it affects several economic variables such as productive profiles, export returns, taxation, investment and demand for labour.

From the productive point of view, the increasing sales of concentrates will generate the closure of hydrometallurgical operations and the reduction of smelting and refining capacity (Badia-Miró and Yañez 2015). As projected by the Chilean Central Bank (2016), this scenario will imply the retirement of more than 40 per cent of the installed capacity in solvent extraction and electro-obtention plants used to produce cathodes in Chile. Of the current 31 active hydrometallurgical operations, only 18 are expected to remain operational by the end of the decade. This could affect the position of exporters in their negotiations of refining charges, thus affecting the liquid return of exports and the companies' taxable profits (Rojas 2009). Consequently, the availability of short-term capital, the wages of workers and the budgets of regional governments that finance public investment programs, subsidies and social assistance will be reduced.

In relation to investment and labour, since concentrate sales contracts are long term, many of these are linked to the financing of mining projects (Fernandez 2015). Therefore, a fall in current copper prices diminishes the ability to negotiate attractive contract terms and affects the viability of future mining projects. This would affect demand for unskilled labour (for construction work) and skilled labour (for mining operation).

Overall, producing more concentrate would affect the regional productive chain and macroeconomic variables. Non-mining production, investment and tax revenues will be affected by the closure of mining sites or the reduction of processed copper. As a result, the productive capacity, investment and tax revenues among regional economies will significantly reduced.

6.2 Simulation results

Two scenarios were simulated based on the general equilibrium model described above. They were a 10 per cent increase (expansive cycle) and a 10 per cent decrease (restrictive cycle) of the short-term price of copper. Since the short-term variation of price has already been shown to modify the long-term price[2], the analysis is developed in the latter context. These stages are meant to analyse the effects that copper price volatility has on the sectors and agents of the main regional copper-producing economies. In order to best isolate the effect of price volatility, royalty costs are not incorporated into this sector. Simulations modify international copper prices in the following manner:

6.2.1 Expansive cycle

A 10 per cent increase on the short-term price of copper generates more currencies inflows through exports and with the subsequent increase in supply, the price of the dollar decreases. The transmission mechanisms of this shock are explained by an increase in the profitability of the mining sector, generating higher levels of investment, production and exports among copper-producing regions. The positive effects on income and on the development of production chains from this expansive cycle offset the effects of sectoral reallocation derived from a rise in copper prices (Rolfe *et al.* 2011). In other words, the increase in the price of copper induces other positive effects that offset the negative effects on non-mining production. One possibility is the income effects increase domestic demand for goods,

[2] Long-term price is understood as 20-year future average.

including demand for non-mining goods. Another possibility is the productive linking of mining with the rest of the economic sectors that can make non-mining production complementary to mining development. The structural model also implies that an increase in production in the non-mining sector must be preceded by an increase in production factors. Accordingly, investment and employment in the non-mining sector also increase. Figure 3 depicts the aggregate effect (in per cent) from a positive short-term copper price variation on the main economic variables of the producing regions.

From a macroeconomic perspective, when international copper prices increase by 10 per cent, the real GDP increases over time until it reaches an increase of around 0.7 per cent, on average. Tarapaca and Antofagasta regions lead the production of copper concentrate and cathodes. Within these regions the expected productive growth potential for the next decade is approximately 20 per cent (De Gregorio and Labbe 2011). Therefore, a copper price expansion cycle would generate an even higher average annual GDP growth within these regions when compared to other productive regions. As a result, it would generate annual growth in investment, tax revenues, and direct and indirect employment.

In addition, imports and exports increase in the first years after a shock, where the increase in imports is almost double that of exports; as the prices return to their long term trend, however, this increase diminishes and both growth rates start to converge.

Investments increase on average around 1.5 per cent during the entire horizon of the simulation, although its greatest impact is 2.1 per cent during the first period of price shock. In addition, consumption increases by 0.7 per cent on average during the course of the simulation. In summary, copper mining accounts for a substantial fraction of the regional economies output, investment and tax revenues. Nor should we neglect the production chain of mining in the generation of indirect economic value of mining production. Copper mining continues to have potential for further development given the

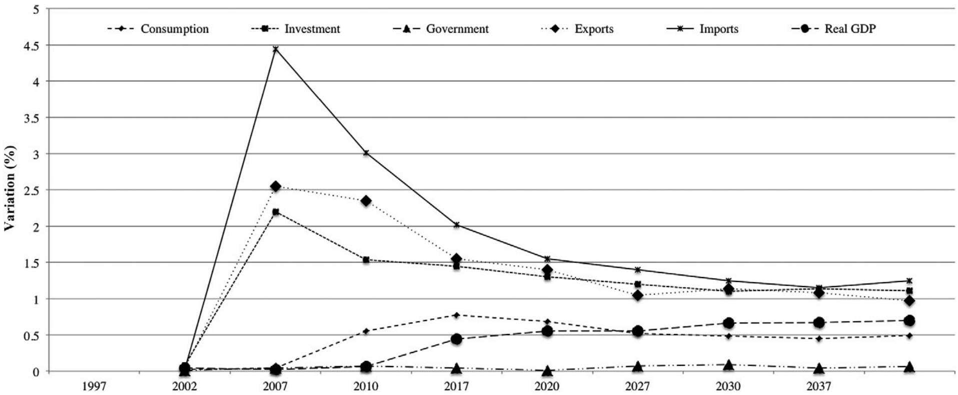

Figure 3 The aggregate effect of an expansive price cycle on regional economic variables (per cent).

comparative advantages that show large estimates of reserves. However, the geographical location of these reserves poses challenges, since they are located in the central zone of the country, where the scale of mining operations is smaller than in the northern zone.

6.2.2 Restrictive cycle

Faced with a fall in international prices, the transmission mechanisms for this shock are modelled to be similar to those found in the expansive scenario. Generally, the copper sector will have lower amount of investment, lower production levels and fewer exports. From the macroeconomic perspective, there is an appreciable restrictive effect on the aggregate variables. A 10 per cent decline in short-term copper prices reduces real GDP by 0.7 per cent; consumption by 0.6 per cent; investment diminishes by about 1.5 per cent; and exports and imports fall by 2.1 and 2.5 per cent, respectively. As well, Elliot *et al.* (1996) and Fernandez (2015) suggest that the effects of a restrictive cycle can be seen in the decrease in the labour productivity index. This phenomenon is not new, as it was found in almost all mining companies during the economic crisis of 2008. The results were lower labour productivity and a direct effect on unemployment in the mining sector. One alternative to counteract this negative situation is the design and implementation of aggressive investment policies to maintain or increase the average annual staff employed during restrictive cycles both in metal mining and in non-metallic mining (Lagos 1997; Phelps *et al.* 2015). This would contribute to stabilise a sector that ranks third in the number of employees employed in Chile (COCHILCO 2016). Figure 3 and Figure 4 depicts the aggregate effect (in per cent) from a negative short-term copper price variation on the main economic variables of the producing regions.

When comparing expansive and restrictive scenarios, it is clear that the regional economic variables present similar but opposite responses to both positive and negative price shocks. However, a negative shock in copper

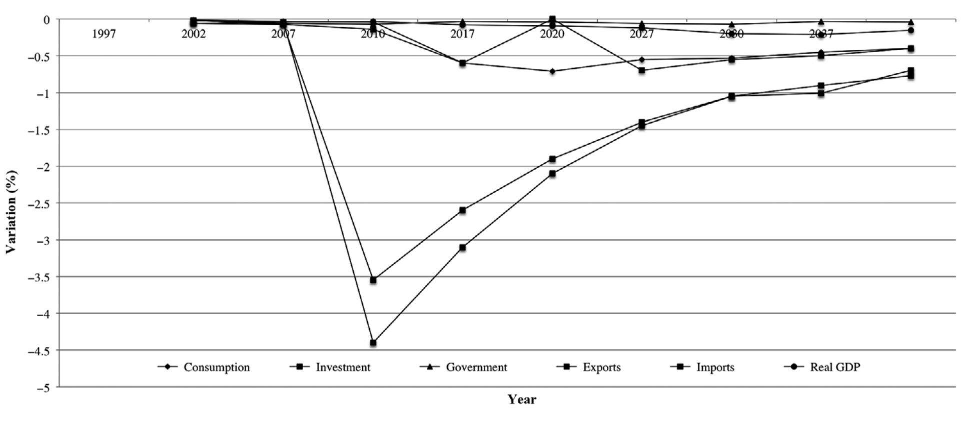

Figure 4 The aggregate effect of a restrictive price cycle on regional economic variables (per cent).

prices is 0.3 per cent more contractive on exports than the contrasting positive shock on such increase. This is consistent with results from other studies (Halada *et al.* 2008) that have shown an analogous positive difference between inverse price shock comparisons, although in terms of aggregate consumption. In terms of real GDP, there is a contraction under a restrictive cycle due mainly to the costs of disinvestment present in the economy. It happens because these types of cycles encourage the movement of capital into more profitable sectors (Brewster & Economics 2009). Under this scenario, non-copper sectors would be mostly favoured, while import sectors would suffer and the higher exchange rate would favour local production through a scenario of substituting imports for intermediate consumption.

From a policy perspective for Chile, the analysis of Ebert and La Menza (2015) is clear in relation to the implications of economic cycles in the domestic economies. They argued that a central element in designing policy aimed towards more balanced growth would look at the need to nurture the relationship between household consumption and private investment. Rising household income and consumption would generate product innovation; private investment would lead to rising labour productivity in non-mining tradable and non-tradable goods sectors, which would, in turn, raise wages and further fuel domestic demand. In this sense, our approach allows policymakers (and others) to disentangle the relationships between price dynamics, shocks and effects on regional economies. Overall, policies could be oriented to compensate for economic losses generated under a restrictive price cycle on producing regions. This situation represents an interesting research avenue for future regional analyses on the effects of commodity price shocks in producing national or regional economies.

7. Conclusions

The impact of natural resources on business cycles and economic development has been an important topic in economic research and policy analysis. Chile is a country rich in natural resources, particularly copper. We studied the impact of copper price shocks on the economies of major Chilean copper-producing regions. Our estimation strategy consisted of two stages: first, an estimation of long-term copper prices using the Wets and Rios approach (2015) and a comparison of these with those forecasted by the Chilean public advisory committee; and second, a general equilibrium model was executed to simulate the effects of expansive and restrictive copper price cycles on major Chilean copper-producing regions. Our estimates showed that the Wets and Rios model yields more homogeneous price projections than those made by the Chilean government, which in turn are very close to variations from negative shocks. Because the government projection is the basis for quantifying fiscal budgets, projecting negative price ranges or prices that are very resilient to international influence could generate significant economic implications. These implications are restrictive effects on regional economies, mainly caused by a fall in total exports, changes in the regional productive profiles and a drop in the sectorial investments. In particular, there is a sharp fall in government and business savings, which directly affects production via lower investment. These results confirm that the majority fiscal revenues, generated by copper sales, benefitted from this trade cycle term multiplier in regional economies.

In terms of price simulations, the paper concludes that under a transitional scenario of an international price increase in copper, and without any policy change, a reduction in the international price of copper produces contraction effects in the Chilean economy. From a macroeconomic perspective, the effect that the restrictive cycle has on the exchange rate is very important. As the exchange rate falls following a drop in copper prices, the relative profitability of other export sectors improves, making capital investment more attractive in those sectors. This situation favours a decrease in local production in a scenario of substituting imports for intermediate consumption. In these cases, the extent of the effects of a positive price cycle was shown not to compensate for the losses of a restrictive cycle. From a political point of view, it is necessary to allocate funds that originate in an expansive cycle towards compensating for the greater losses to come under a scenario of lower prices.

Data availability statement

The data that support the findings of this study are available from the corresponding author upon request.

References

Akram-Lodhi, A. (2007). Land, markets and neoliberal enclosure: an agrarian political economy perspective, *Third World Quarterly* 28, 1,437–1,456.

Badia-Miró, M. and Yañez, C. (2015). Localization of industry in Chile, 1895–1967: mining cycles and state policy, *Australian Economic History Review* 55, 256–276.

Beghin, J., Dessus, S., Roland-Holst, D. and van der Mensbrugghe, D. (1996). General equilibrium modelling of trade and the environment, OECD Development Centre Working Papers 116, OECD Publishing.

Böwer, U., Geis, A. and Winkler, A. (2007). Commodity Price Fluctuations and Their Impact on Monetary and Fiscal Policies in Western and, Central Africa, ECB Occasional Paper No. 60. Available from URL SSRN https://ssrn.com/abstract = 967605. [accessed 15 January 2018].

Bravo-Ortega, C. and De Gregorio, J. (2006). The relative richness of the poor? Natural resources, human capital and economic growth, in Lederman, D. and Maloney, W.F. (eds), *Natural Resources, Neither Curse nor Destiny*. World Bank, Washington, DC.

Brewster, N. and Economics, R. (2009). Outlook for commodity markets. Rio Tinto Inc, MF Global Seminar.

Calvo, G. and Mendoza, E. (1998). Empirical puzzles of Chilean stabilization policy, Seminar on Chile Development Lessons and Challenges organized by the Economic Development Institute of the World Bank, held in Washington D.C., December 17–18, 1997, March 6.

Chen, Y.C., Rogoff, K.S. and Rossi, B. (2010). Can exchange rates forecast commodity prices? *The Quarterly Journal of Economics* 125, 1,145–1,194.

Chilean Central Bank (2016). *Estado Anual de Cuentas Nacionales*. Available from URL http://www.bcentral.cl/es/faces/estadisticas/CNacionales/CNacAnuales?_afrLoop=796847078274027&_afrWindowMode=0&_afrWindowId=mikxdiz95_95#!%40%40%3F_afrWindowId%3Dmikxdiz95_95%26_afrLoop%3D796847078274027%26_afrWindowMode%3D0%26_adf.ctrl-state%3Dmikxdiz95_167 [accessed 20 March 2016].

Corporacion Chilena del Cobre (COCHILCO) (2016). Mining production and trade. Available from URL http://www.cochilco.cl/english/statistics/production.asp. [accessed 12 May 2016].

Cuddington, J. and Jerrett, D. (2008). Super cycles in real metals prices? IMF staff Papers, 541–565.

Ebert, L. and La Menza, J. (2015). Chile, cooper and resource revenue: A holistic approach to assessing commodity dependence, *Resources Policy* 43, 101–111.

Elliott, G., Rothenberg, T.J. and Stock, J.H. (1996). Efficient tests for an autoregressive unit root, *Econometrica* 64, 813–836.

Fernandez, V. (2015). Commodity price excess co-movement from a historical perspective: 1900–2010, *Energy Economics* 49, 698–710.

Frankel, A. and Rose, K. (2010). Determinants of Agricultural and Mineral Commodity Prices, HKS Faculty Research Working Paper Series RWP10-038. John F. Kennedy School of Government, Harvard University.

De Gregorio, J. and Labbé, F. (2011). Copper, the real exchange rate and macroeconomic fluctuations in Chile, Central Bank of Chile Working Papers No 640.

Halada, K., Shimada, M. and Ijima, K. (2008). Decoupling status of metal consumption from economic growth, *Materials Transactions* 49, 411–418.

Irwin, S., Sanders, D. and Merrin, R. (2009). Devil or angel? The role of speculation in the recent commodity price boom (and bust), *Journal of Agricultural and Applied Economics* 41, 377–391.

Lagos, G. (1997). Developing national mining policies in Chile: 1974–1996, *Resources Policy* 23, 51–69.

Mardones, D. (2012). Chile: Elaboración de un modelo de equilibrio general computable y su aplicación a la región del Bío Bío, Revista de la CEPAL N 106.

Medina, L. (2010). The dynamic effects of commodity prices on fiscal performance in Latin America, *Working Paper* WP/10/192, International Monetary Fund.

Medina, J.P. and Soto, C. (2007). The Chilean business cycles through the lens of a stochastic general equilibrium model, Central Bank of Chile Working Papers N° 457.

Oyan, R., de Miguel, C., Pereira, M. and Lagos, C. (2008). *Impactos Económicos y Sociales de Shocks Energéticos en Chile: Un Análisis de Equilibrio General, Documentos de trabajo N° 466*. Banco Central de Chile, Santiago.

O'Ryan, R., de Miguel, C.J. and Miller, S. (2003). The Ecogem-Chile Model: A CGE Model for Environmental and Trade Policy Analysis. Central Bank of Chile Working Papers.

Phelps, N., Atienza, M. and Arias, M. (2015). Encore for the enclave: The changing nature of the industry enclave with illustrations from the mining industry in Chile, *Economic Geography* 91, 119–146.

Radetzki, M., Eggert, R., Lagos, G., Lima, M. and Tilton, J. (2008). The boom in mineral markets: How long might it last? *Resources Policy* 33, 125–128.

Riffo, L., Becerra, H., Acevedo, R., Morgado, M. and Villegas, O. (2006). *Matrices Insumo Producto Regionales*. *Series Estadistica y Economia*. Instituto Nacional de Estadistica, Santiago, Chile.

Rojas, C. (2009). Matriz de Contabilidad Social y Análisis de Multiplicadores Contables para la Región Metropolitana de Santiago. Tesis Magister en Economía Aplicada. Facultad de Ciencias Físicas y Matemáticas, Universidad de Chile. 289 pp.

Rolfe, J., Gregg, D., Ivanova, G., Lawrence, R. and Rynne, D. (2011). The economic contribution of the resources sector by regional areas in Queensland, *Economic Analysis and Policy* 41, 15–36.

Spilimbergo, A. (2002). Copper and the Chilean Economy, 1960-98, *The Journal of Policy Reform* 5, 115–126.

Thorbecke, E. (2000). The use of social accounting matrices in modeling. 26th General Conference of the International Association for Research in Income and Wealth Cracow, Poland (Vol. 27)

Wets, R.J. and Rios, I. (2015). Modeling and estimating commodity prices: copper prices, *Mathematics and Financial Economics* 9, 247.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. General Database.