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Evaluation of regional impacts of the copper industry in Chile

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ABSTRACT

This paper presents selected results of the research project “Development of Sustainable Mining Strategies in Chile with a Regionalized National Model” conducted by GWS (Germany) and the University Adolfo Ibáñez (Chile). Chile has about 30 % of the worldwide copper reserves and the copper industry dominates the Chilean economic development. The goal of the project is to figure out which region(s) and to what extend are most vulnerable due to the strong concentration on copper mining and processing.

First, a macro-econometric input-output (IO) model for Chile (COFORCE – Copper FORcasting ChilE) was built from scratch in line with the INFORUM (Interindustry FORcasting at the University of Maryland) modelling approach. Such models are built bottom-up and the IO tables are embedded consistently into a macro-econometric framework. The economic core of the model consists of IO tables showing the supply linkages and demand with a high level of detail including the copper mining and processing industry, the system of national accounts describing the economic circuit for the main economic sectors a. o. private households, companies and government from production, income generation and redistribution to consumption and the labour market.

Second, due to the importance of Chilean copper exports, the COFORCE model is linked to the bilateral trade model TINFORGE which captures world trade between 153 countries for 33 product groups including copper as well as world market prices for copper and other important raw material products. The national COFORCE model receives export demand and import prices from the world model according to its global market shares.

Third, the COFORCE model was regionalized by using an Interregional Input-Output table. The national and 15 regional models for Chile are linked via final demand components and industries by applying a top-down approach. Therefore, regional economic growth is mainly driven by the industry structure and inter- and intraregional trade.

This set of three projection and simulation models considers the main aspects regarding copper: 1. It is the main exporting product, 2. It has a huge impact on the economic development and 3. The copper industry is regionally differently concentrated. The modelling tools are applied for the evaluation of alternative economic scenarios, e. g. copper export scenarios at the national and regional level.

The main focus of this paper is to introduce the methodology used to regionalize the national model COFORCE, to explain the main transmission channels and to present regional modelling results.

1 MOTIVATION

Chile has about 30 % of the worldwide copper reserves and the copper industry dominates the Chilean economic development. About 10 % of GDP is related to the mining sector and 45 % of Chileans exports are related to copper (Comelli, Pérez Ruiz 2016). The dependency on copper especially on exports is high. The most important purchasers of Chilean copper are China and Japan, each with about 30 %, followed by India and Korea.

Currently, Chile performs well due to a strong copper demand and increasing copper prices. Because of the excellent electrical and thermal conductivity of copper, it is intensively used in the electrical, telecommunication, computer and automotive industry as well as the energy sector. Global trends such as the digitalization and the energy transition – the latter affects mainly the energy and transportation sector – will further boost the demand for copper. For example, according to the International Copper Association (ICA) electrical cars need 20 to 60 kg more copper than conventional cars (Toyama 2017, Warren Centre 2016, McHugh 2017). Furthermore, copper is a main component in renewable energy technologies such as solar and wind power as well as in the power grid.

China is still the main copper importer and the dependency on a major customer conceals a great risk. Other challenges are the high copper price volatility and strengthening competitors e. g. in Peru, Panama and Mongolia (Busch 2018).

The economic effects of a lower demand for Chilean copper exports are evaluated in a scenario analysis. In addition to the macroeconomic impacts, the focus is also on regional effects to figure out which region(s) and to what extend are most vulnerable due to the strong concentration on copper mining and processing.

In section 2 the methodology is explained in detail. Afterwards, the scenario settings and results are described at the national and regional level. In Section 4 a summary and further research are presented.

The modelling framework and the results presented in this conference paper are created within the framework of the project “Development of sustainable strategies in the Chilean mining sector through a regionalized national model” which is funded by the German Federal Ministry of Education and Research. It supports the cooperation and exchange in knowledge between the Chilean team of the University Adolfo Ibañez in Viña del Mar and the Institute of Economic Structures Research (GWS) in Osnabrück, Germany. The COFORCE model is handed over to the Chilean partners so that they can carry out scenario analyses independently. To make the model easier to use, it is equipped with the graphical user interface IMAGINE which supports the user in scenario design, calculation and evaluation. Further information on the project can be found at http://www.coforce.cl/.

2 METHODOLOGY

The basis of the economic analysis follows a two-stage approach: initially, a regionalized macro-econometric input-output model with a link to a world trade model was developed. In a next step, the model was used to run and evaluate an export scenario (section 3). The following subsections report briefly about the modelling framework.

The modelling framework consists of three models which are interrelated: the world trade model TINFORGE (section 2.1), the national model COFORCE (section 2.2) and the regional model for 15 Chilean regions (section 2.3, Appendix 1). The TINFORGE model determines world trade for different countries amongst them Chile and its trading partners. The national COFORCE model receives the export demand and import prices from the TINFORGE model which has the advantage not to be determined exogenously as it is in many national models. The regional economic development depends on the economic growth by industries as projected at the national level by using a top-down approach (Figure 1).

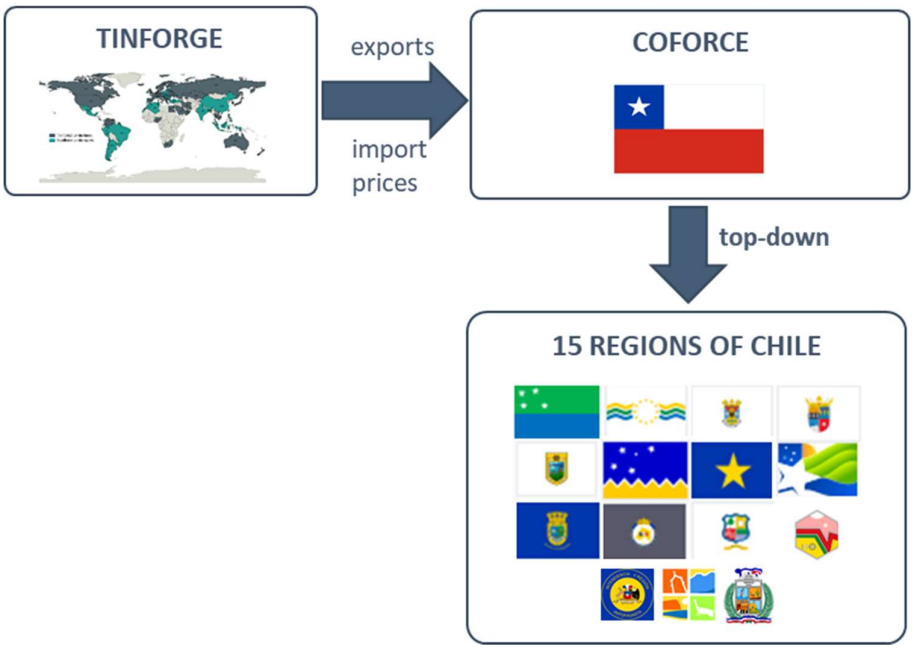

Figure 1: **Modelling framework**
Source: Own presentation

2.1 TINFORGE

TINFORGE (Trade in the INterindustry FORecasting GErmany Model) depicts the bilateral trade as given in the OECD's bilateral trade matrices for 155 countries – amongst them is Chile – and 33 product groups. Chilean exports are determined by the import demand of the trading partners of Chile. Import demand, in turn, is described in 80 of the 155 countries by a country-specific macroeconomic model. For the remaining countries, imports follow the Eurostat or IMF forecasts as well as trend forecasts.

The simple macroeconomic models project GDP from the demand side. Around 30 macroeconomic aggregates are estimated for each of these 80 national models. These include GDP and its components such as household demand and investments in price-adjusted and nominal values, the associated price indices and four key labour market indicators (economically active population, employment, unemployment and wages). Imports are strongly correlated to domestic demand. An additional explanatory variable is real export demand representing the position of a country within the global value chain. Export-induced imports are one globalization aspect that implies offshoring of production processes and the necessity of importing intermediate products such as raw materials or components. The model also incorporates UN demographic projections.

TINFORGE is primarily based on OECD data, complemented where necessary by EUROSTAT, UN and International Monetary Fund (IMF) data. Figure 2 shows at a glance the modelling approach for TINFORGE.

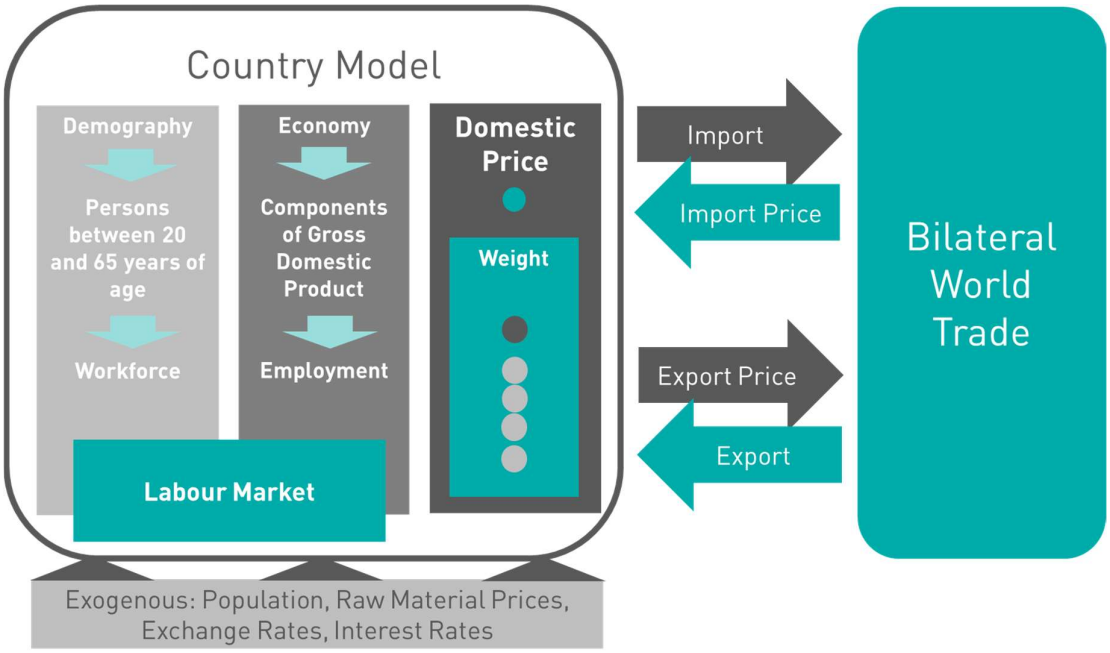

Figure 2: **Simplified sketch of the world trade model TINFORGE**
Source: Own presentation

Export demand by country is derived from the bilateral trade matrices by product groups and depends on all trading partners' import demand. The country models depict no structural information for exports and imports but the bilateral trade matrices (BTM) do. Thus, the product group shares of the BTM are used to derive exports by product groups for each country including Chile.

A more comprehensive description of the world trade model are given in Mönnig, Wolter (2019) and Großmann, Mönnig, Wolter (2015).

2.2 MACRO-ECONOMETRIC INPUT-OUTPUT MODEL FOR CHILE

The macro-econometric IO model COFORCE[1] (COpper FORcasting ChilE) was developed to analyse Chiles economy in general and in especially its economic dependency on copper for the long run (until 2035). It is a single country projection and simulation model and based on a comprehensive data set using original Chilean data obtained from the project partners of the University of Adolfo Ibanez. The dataset is retrieved from official data producers like the Chilean Central bank or the National Statistical Bureau.

Figure 3 shows a simplified illustration of the COFORCE model. The core of the model is the input-output framework – IO tables and national accounts – showing the total economy as well as 73 industries. The IO table is embedded into the national accounts where for example disposable income and net lending/borrowing is derived for each of the sectors e. g. private households, firms and government.

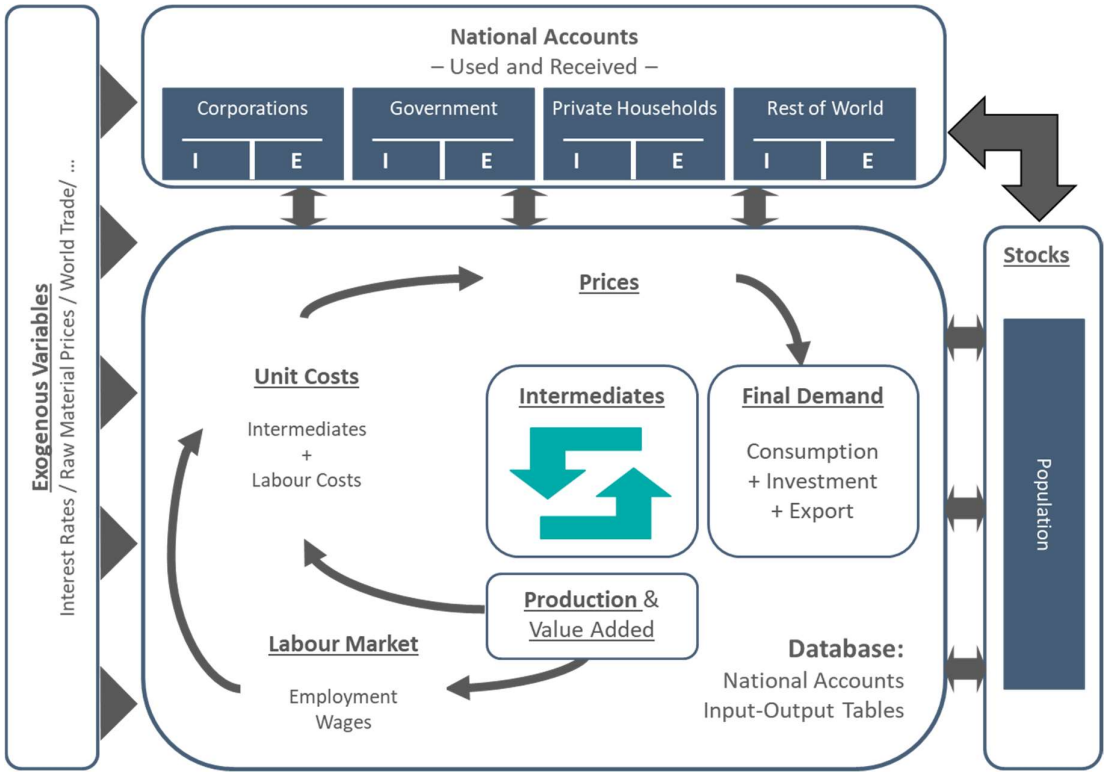

Figure 3: **Simplified illustration of the modelling framework of COFORCE**
Source: Own presentation

The link between demand and supply is given from the Leontief production function. Furthermore, the IO table shows the cost structure for each industry given by demand for intermediate goods and used primary inputs such as compensation for employees, depreciation, net taxes on production. Prices are derived by using a unit cost approach considering the single cost components. Furthermore, depending on the competitive situation, a profit

[1] A more detailed description of the methodology is given in Mönnig, Bieritz (2019).

margin is also taken into account in pricing. Production prices plus net taxes on goods determine purchasers prices. The latter determine, in addition to disposable income, the demand of private households.

Supplementary data are population by age groups, employment and wages by industries. Population at working age determines the work force. Labour demand is determined at industry level and related to real production and wages by industries. Increasing real wages tend to lower employment while a higher production level will increase employment. The macroeconomic wage rate is determined by using a Phillips curve approach.

The economic modelling follows the approach of the INFORUM [2] group (http://inforumweb.umd.edu/) which is characterised by bottom-up modelling and total integration (Almon, 1991). The former indicates that each industry respectively product group is modelled individually and macroeconomic variables are calculated through explicit aggregation. The latter describes a complex and simultaneous solution, which considers interindustry dependence as well as the complete economic circle from generation of income, distribution and redistribution of income as well as the use of income for goods and services. Thus, the input-output tables are fully integrated in the national accounts and each sector such as government, private households, companies and rest of world is treated individually (Ahlert et al. 2009).

Furthermore, it is highly endogenized; only a few variables such as population forecasts, central bank interest rates, raw material prices, world trade (section 2.1) and exchange rate are given exogenously by either third party information or by setting own assumptions. Due to its interdependent and detailed modelling structure this kind of model allows for in-depth analysis on industry and sectoral level.

As other models from the INFORUM group and Cambridge Econometrics (https://www.camecon.com/), COFORCE combines IO modelling and econometric methods. The model comprises behavioural (estimated) equations and definitions. The behavioural equations, e. g. final demand components and employment, are based on the assumption of bounded rationality rather than strictly optimizing behaviour. The model is tested and equations are adapted until the development of endogenous variables matches the historical data very closely.

In contrast to many CGE models, the model is validated empirically instead of being calibrated to the model parameters on a given benchmark or obtaining elasticity values from literature. Furthermore, the theoretical foundation of the models differ. CGE models focus on equilibrium situations most often following neo-classical tradition. The applied model here, however, borrows from evolutionary economics (Nelson, Winter 1982) and features technological change, imperfect competition, interdependencies, and partially sticky prices.

There are also many features in common with standard CGE models (Almon 1991, West 1995). The data set (input-output tables and national accounts) as well as the non-linear functions are of similar nature. Both model types consider supply constraints, prices and the feedback loop between income and household demand.

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[2] Interindustry Forecasting at the University of Maryland

2.3 INTERREGIONAL INPUT-OUTPUT MODEL FOR CHILE

The regionalization is carried out using a top-down disaggregation of the national results. The basis of the regional modelling is an interregional IO (IRIO) model for Chile with full specification of interregional flows (Haddad et al. 2002, 2018). The IRIO is given for the year 2013 and comprises the 15 Chilean regions and 10 industries.

The COFORCE model and the regional models are linked by the final demand components household consumption, government consumption, investment and exports.

First, each of the final demand components at the national level is aggregated so that it fits the industry classification of the IRIO. Afterwards, the final demand by components and industries at the national level needs to be spilt accordingly to the demanding and supplier regions. For this a 'market share indicator' and a 'demand indicator' of a region and each industry is determined.

The regional 'demand indicator' RDI_i shows the final demand share (investments, household or government demand) by industries i of a demanding region $fd_{i,rd}$ in final demand determined at the national level fd_i without specifying the supplier regions.

$$RDI_i^{rd} = \frac{fd_i^{rd}}{fd_i}$$

$$\forall \in i, i = [1;10], \qquad \forall \in rd, rd = [1;15]$$

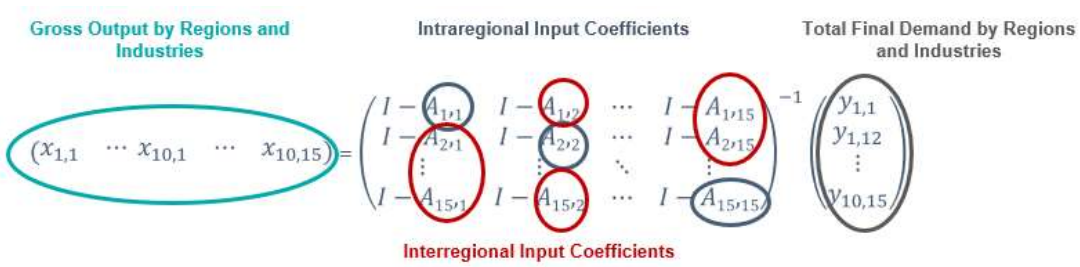
The regional 'market share indicator' $RMI_{i,rd,ro}$ considers the origin of the final demand by industries. For each demanding region rd and final demand by industries $fd_{i,rd}$, the share of the supplier regions (regions of origin) ro are calculated.

$$RMI_i^{ro,rd} = \frac{fd_i^{ro,rd}}{\sum_{ro=1}^{15} fd_i^{rd}}$$

$$\forall \in i, i = [1;10], \qquad \forall \in rd, rd = [1;15], \qquad \forall \in ro, ro = [1;15]$$

By multiplying the regional 'demand indicator', the regional 'market share indicator' and the final demand components at the national level, the final demand as given in the IRIO can be projected. Up to now, both indicators are constant over time.

Gross output by regions and industries can be derived by applying the following equation (Miller, Blair 2009).



The intraregional and interregional input coefficients are constant over time but can be made flexible by linking them to the flexible coefficients in the national IO table.

For the calculation of employment effects at the regional level, a top-down procedure is applied. Employment and production by industries at the national level are aggregated to the same classification as used at the regional level and labour productivity is derived. At the regional level the labour productivity is calculated as well. The labour productivity by industries from the national level is then transferred to the regional level. It is assumed that in each region the growth rate of labour productivity by industry is the same. From the regional production by industries and the labour productivity regional employment can be derived.

3 SCENARIO ANALYSIS

Macro-econometric IO models are suitable for projections and scenario analysis. The most basic projection assumes that past behaviour is also effective in the future (baseline scenario). Scenario analysis is a method to analyse the impact ("what if") of policy measures or adjusted exogenous variables on future developments. A scenario consists of one or a set of consistent assumptions which are fed into the model. Comparing two scenarios reveals differences that can be interpreted as reactions to the impulses induced by the assumptions. The differences in results illustrate the impacts of the initial changes at a specific point in time and over time (Figure 4).

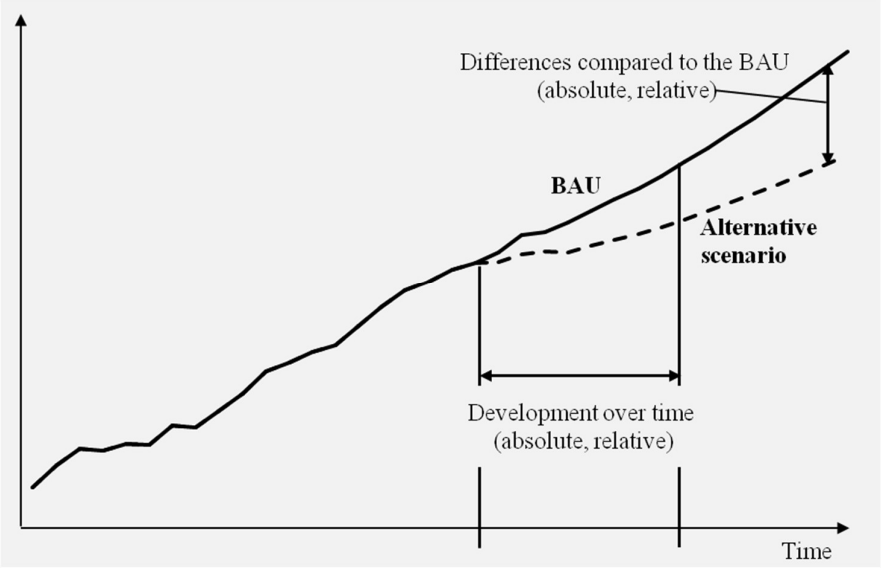


Figure 4: **Comparing scenarios**
Source: Own representation

3.1 THE EXPORT DEMAND SHIFT TOWARDS PERU

To analyse the dependency and vulnerability of the Chilean economy and its regions of copper, a demand shift towards the rising copper supply of its northern neighbour Peru has been worked out. The rationale behind the export scenario is that copper demand is still

increasing worldwide especially due to the growing markets for electromobility and renewable energy (Toyama 2017, Warren Centre 2016, McHugh 2017). Chile will probably lose world market shares because Peru increases its copper production through the exploration of the Las Bambas mine (Chong et. al. 2016, La República 2017, Taj 2018).

3.1.1 SCENARIO ASSUMPTIONS AND SETTINGS

The starting point is a reduction in Chilean copper exports to India and China of 5 % each p. a. for a period of five years (2018 – 2022) compared to the baseline scenario. Chileans copper exports are still increasing but at a lower growth rate than in the baseline scenario (Table 1).

In 2017, the year before the intervention, the export shares of China are of 33,8 % and the Indian shares amounts to 12,9 %. The export shares of copper going to India and China decreases over time and amount to 31,7 % for China and 12,7 % for India in 2022. After the five years period, a return to the former export demand is assumed.

Table 1: Scenario settings

	2017	2018	2019	2020	2021	2022
BASELINE copper export, 2017=100	100	106,1	108,8	111,7	114,7	117,8
SCENARIO copper export, 2017=100	100	103,5	103,7	103,8	104,0	104,2
China, in %	33,8	33,7	33,0	32,7	32,3	31,7
India, in%	12,9	12,9	13,1	12,9	12,8	12,7

Source: Own calculations with COFORCE

3.1.2 SCENARIO RESULTS

The initial change in copper exports leads to a decrease of total export in constant prices of -5.6 % compared to the baseline scenario (Figure 6).

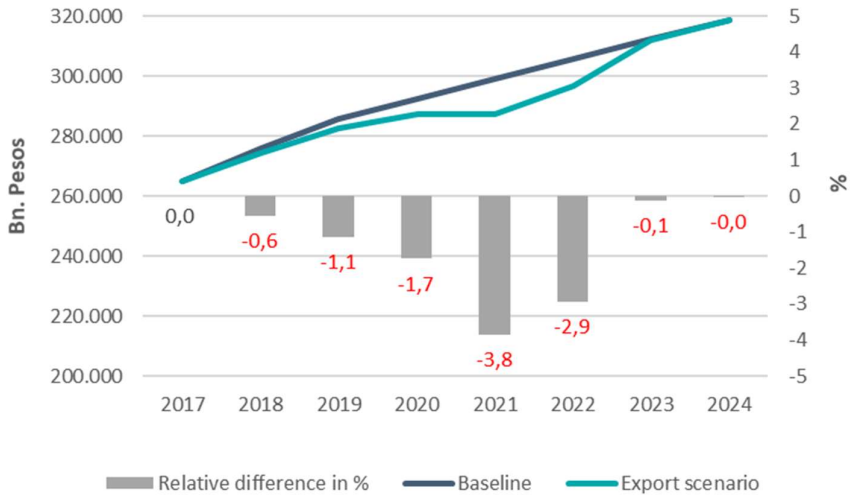


Figure 5: Production in constant prices, 2016-2024 in Bn. Peso
Source: Own calculations with COFORCE

This lower demand reduces the whole Chilean production in constant prices by -2.9 % in 2022 compared to the baseline scenario, whereby the production growth rate slows down until 2021 and starts to recover in the last year. In Figure 5 the development of production in constant prices is contrasted for the baseline scenario (blue line) to the export scenario (green line). The grey bars show the relative difference of the production between both scenarios (right axis).

Focusing on the industry level, the relative decrease of the production of the copper industry itself by nearly 14 % compared to the baseline scenario is notable. The production of the manufacturing of machinery, electrical and transport equipment are strongly affected as well as the energy production and railway transport (Table 2). To summarize, the industries which are strongly related to the copper mining industry are affected most.

Table 2 **Top ten affected industries in production (constant prices) in the export scenario compared to the baseline scenario in % (2018-2022)**

	2018	2019	2020	2021	2022
Copper Mining	-2.8	-5.5	-8.4	-11.4	-13.8
Manufacture of machinery and electrical equipment	-2.0	-3.9	-5.9	-12.1	-9.6
Manufacture of transportation equipment	-1.5	-2.9	-4.7	-8.3	-7.8
Electricity supply	-1.0	-2.2	-3.3	-5.5	-6.0
Gas supply	-0.9	-1.8	-2.7	-4.6	-4.6
Manufacture of rubber products	-1.0	-1.9	-2.8	-3.7	-4.3
Railway transport	-0.8	-1.7	-2.6	-4.7	-4.3
Manufacture of machinery and non-electrical equipment	-0.7	-1.4	-2.2	-4.7	-3.8
Insurance companies	-0.6	-1.2	-1.8	-4.6	-3.1
Oil Extraction	-0.6	-1.1	-1.7	-4.2	-3.0

Source: Own calculations with COFORCE

Lower copper exports weaken the Chilean GDP which decreases up -4 % compared to the baseline scenario. One consequence of the weaker copper production is a decline in total employment of up to -1.2% compared to the baseline scenario. As a result, the income and consumer demand (-4% compared to baseline in 2022, Figure 6) of private households is lower. Decreasing imports (-1.6 % in 2022) compared to the baseline scenario dampen the negative effect on the GDP.

Government revenues in Chile are heavily dependent on copper mining. Due to lower copper exports, governmental disposable income is reduced by 6.7 % (2022). Codelco as a state-owned company has to deliver around 90 % of its profits to the government, 10 % remains for the company to invest. If governmental income decreases, government spending and investments will decline as well.

Additionally, lower economic and employment growth reduce revenues from income and product taxes. Consequently, its possibilities to enforce intended policy measures are limited.

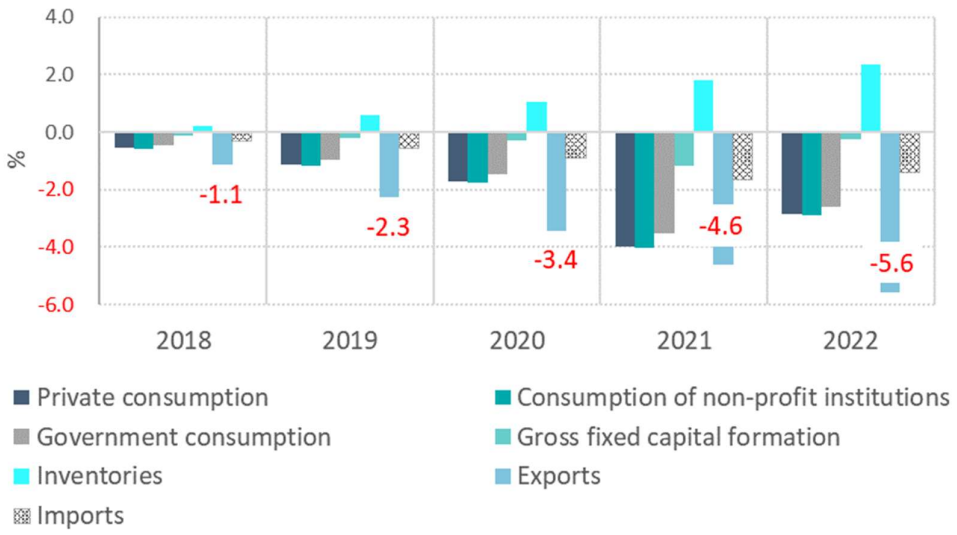


Figure 6: **Relative differences in GDP components compared to the baseline scenario**, Source: Own calculations with COFORCE

The impacts for the 15 regions are as follows:

According to the IRIO in 2013, the export shares of mining products (incl. copper) are highest in Antofagasta 49 % resp. eleven billion Peso. In this region, one of the biggest copper mines worldwide "Chuquicamata" is located. Six other regions have an export share of about 7-9 % which accounts to at max two billion Peso (Figure 7).

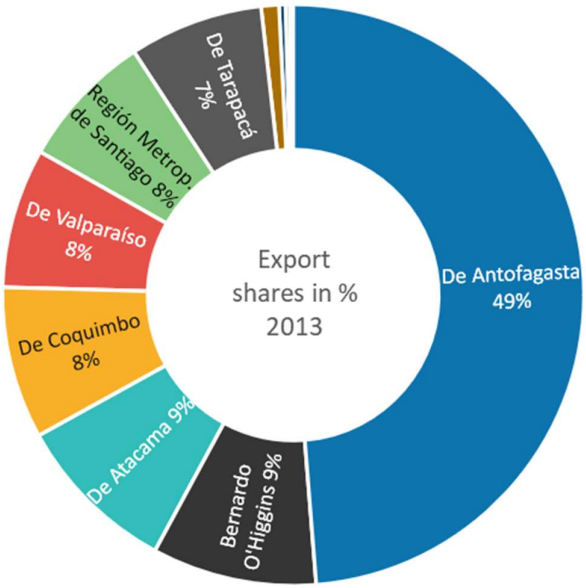


Figure 7: **Regional export shares in % (2013)** Source: IRIO 2013

The weakened copper exports affects Antofagasta most. Production and employment are negatively affected as well. While gross output in mining affects only regions with mining

industry (direct impacts), all regions are effected when looking at total output due to inter-industry and inter-regional effects (Figure 8).

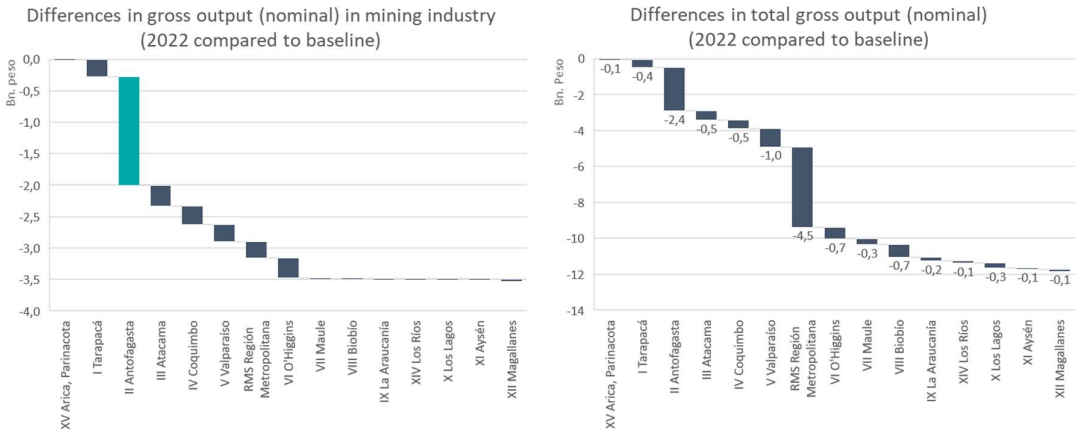


Figure 8: **Impacts on nominal gross output for mining industry (left figure) and all industries (right figure) in the export scenario compared to the baseline, 2022 in Bn. Peso**
Source: Own calculations with COFORCE

Depending on the economic importance of a region, the income-induced demand effects determined at the national level influence, among others, investment and private consumer demand at the regional level.

The majority of the investments take place in the construction (55 % resp. 17.5 Bn. Peso) and the manufacturing industry (27 % resp. 8.5 Bn. Peso). From a regional point of view, the regions "X De Los Lagos" with 43 % (corresponds to 14 Bn. Peso), followed by "IV De Coquimbo" (10 %), "VI Bernardo O'Higgins" (9 %) and "VIII Del Biobío (6 %)" are the top investment regions. The first three regions together account for 62% of total investment demand (Figure 9).

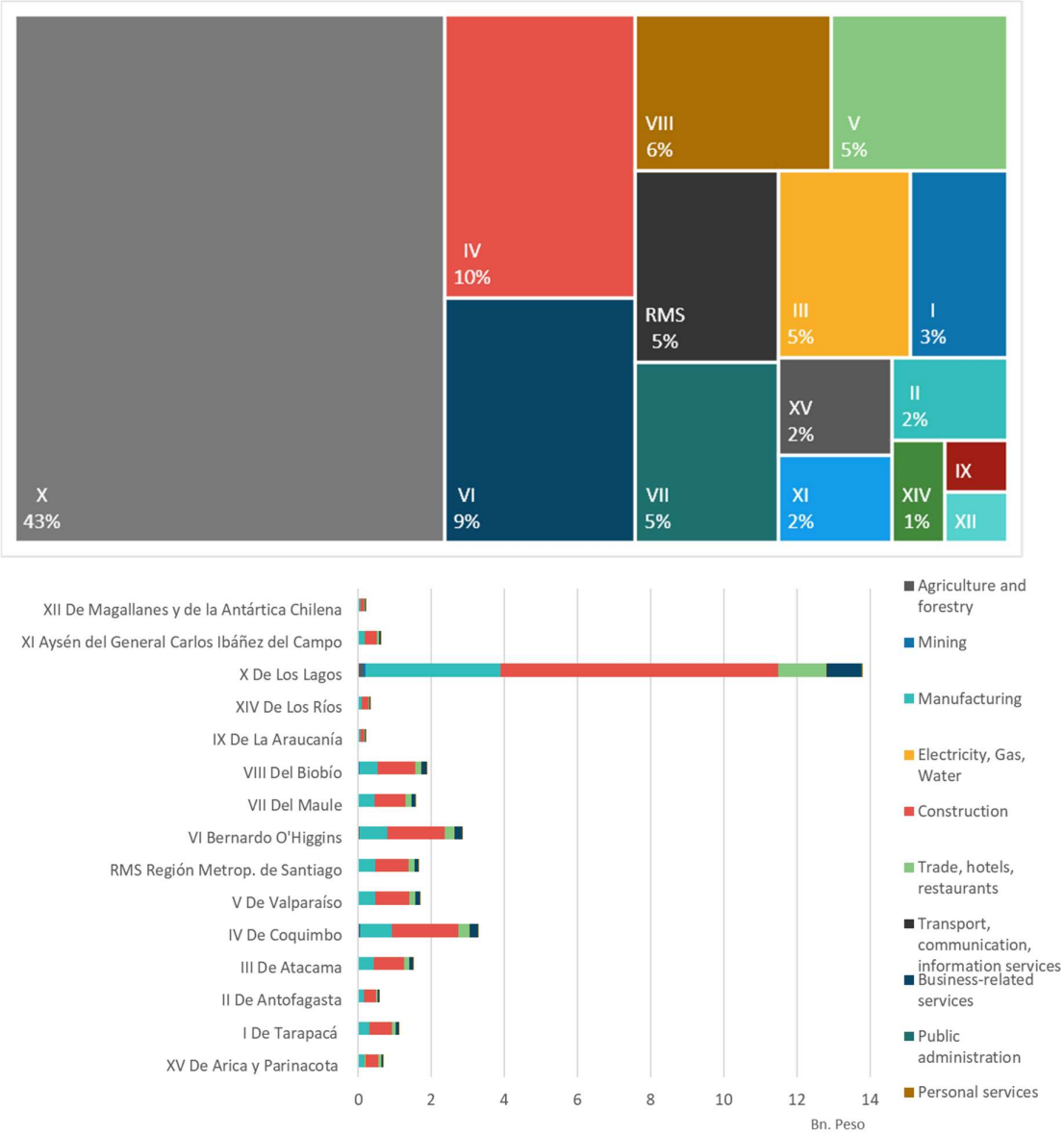
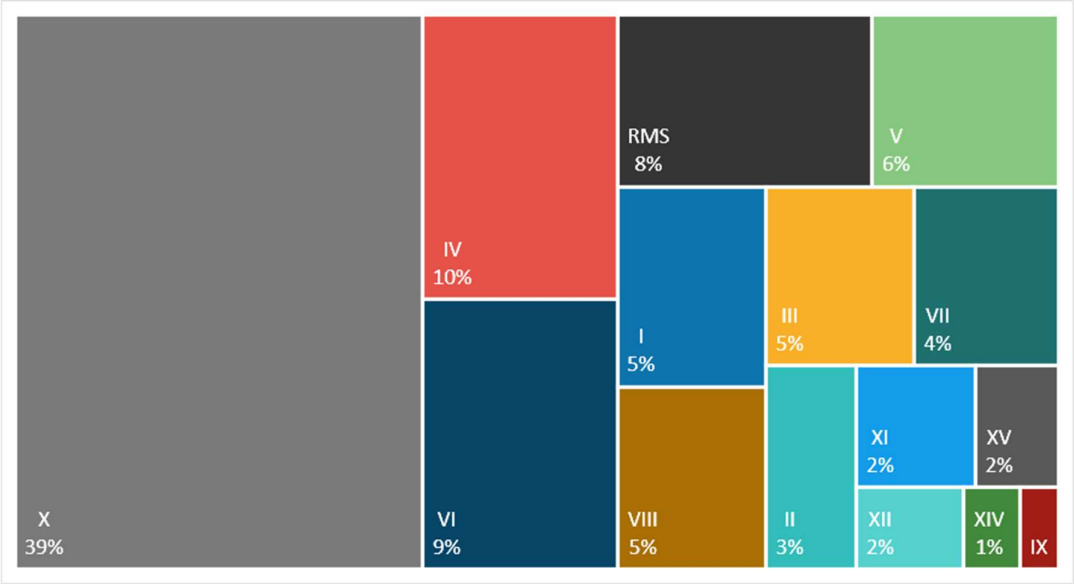


Figure 9: **Regional investment shares in %, 2013 (upper figure)**
Regional investments by industries and regions in Bn. Peso, 2013
Source: IRIO 2013

Private consumer demand is distributed somewhat more evenly among the industries as observed in investment demand. Manufacturing has the largest share at 29 %, including the food industry. Together with 'trade, hotels, restaurants' (20 %), 'business-related services' (19 %), 'personal services' (16 %) and 'transport, communication and information services' (11 %), these industries cover 95 % of total household demand (Figure 10).

The analysis of the regional distribution shows the dominance of the central and central southern regions such as "X De Los Lagos" (39%), "IV De Coquimbo" (10%), "VI Bernardo O'Higgins", "RMS Región Metrop. de Santiago" (8%) and "V De Valparaíso" (6%). The distribution thus follows the industrial occupation of the regions rather than the population structure. The Región Metropolitana de Santiago is home to 41 % of the population, but

only 8 % (4th place in the regional ranking) of the demand for private households is generated in the region. In contrast, "X De Los Lagos" ranks 5th with 5 % of the population, but first in the ranking of private consumption shares. In this region, the agriculture, forestry and fisheries as well as the associated manufacturing industries and tourism are strongly represented in this region.



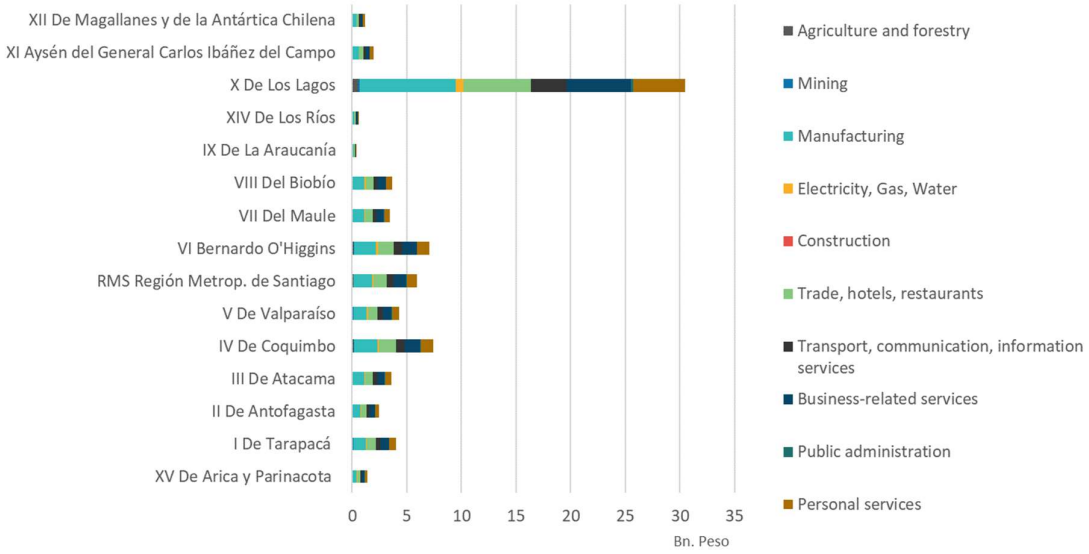


Figure 10: **Private consumption shares by industries in %, 2013 (upper figure) Regional private consumption by industries and regions in Bn. Peso, 2013 (lower figure)**
Source: IRIO 2013

The effects calculated at the national level for the demand of private households, the government and investments are transferred top-down to the regions. Figure 11 shows the regional results.

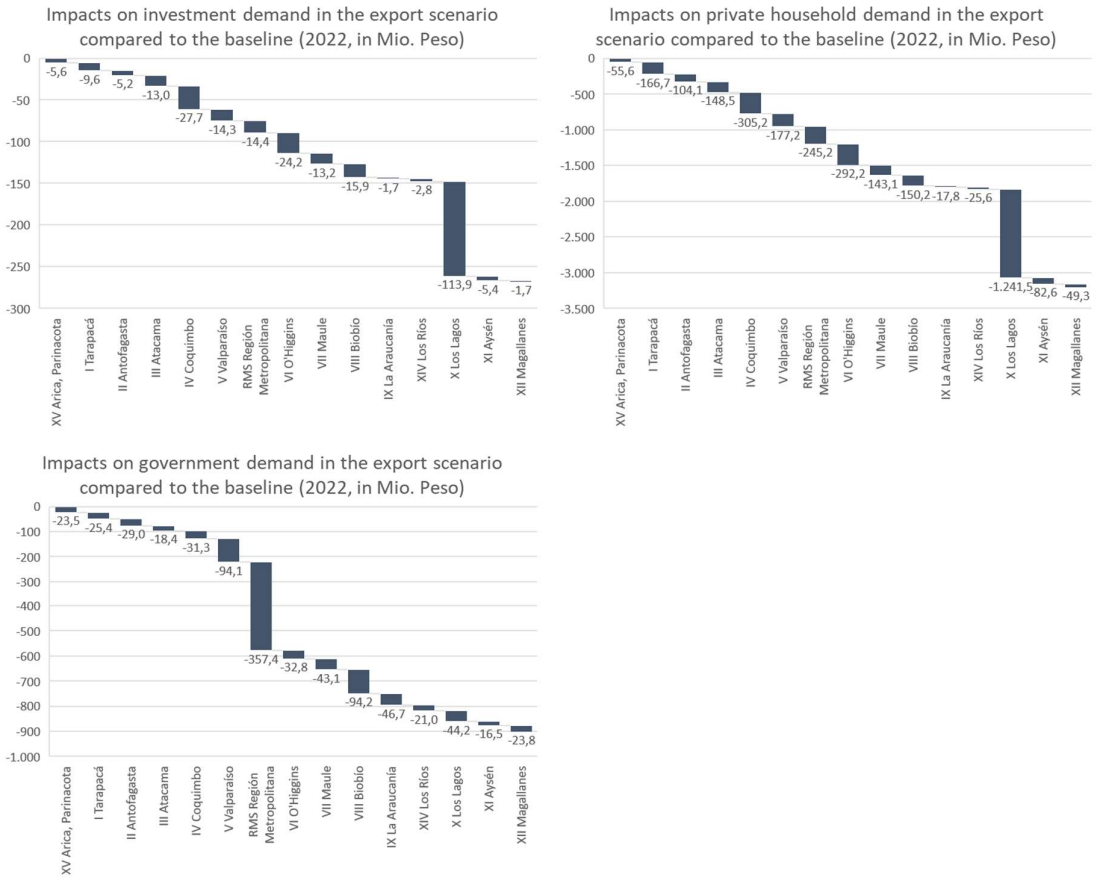


Figure 11: Impacts on final demand components in the export scenario compared to the baseline (2022, in Mio. Peso)
Source: Own calculations with COFORCE

In terms of investment demand, the region "X Los Lagos" shows the strongest decline in comparison to the baseline due to the high importance of investment demand in this region. Government consumption in "RMS Región Metropolitana" is declining the most, as Santiago de Chile, the capital, is home to the largest number of public institutions. Compared to the baseline, private consumer demand is weakening the most. "X Los Lagos" shows the strongest reaction due to the economic structure.

4 SUMMARY AND FURTHER RESEARCH NEEDS

The scenario analysis shows, that an export reduction of copper affects the development of all industries in Chile through the customer and supply relationships. The initial reduction in copper exports will primarily affect the northern regions of Chile, where the copper mines are located. Upstream and downstream industries are subsequently affected by demand adjustments in the mining sector. Due to the different economic structures in the Chilean regions, the economic consequences in the regions are also diverse. The results show both

the effects of the inter-industry interdependencies and the interregional relations. The results so far are based on the assumption of constant inter-industry and interregional trade relations between the Chilean regions. In further scenarios, the effects of flexible structures will be analysed.

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Appendix 1: **Chiles Regions**
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