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Direct economic return to government of public geoscience information investments in Chile

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ABSTRACT

This article presents the first attempt to evaluate the direct economic return of the provision of public geoscience information in Chile. To achieve this goal the study uses multiplier effect ratios through the value chain of PGI and a probabilistic discounted cash flow model to evaluate the economic returns of different scenarios for the ongoing governmental program mandated to generate country-scale geological information, named the National Geological Program.

The study shows that, in average, every dollar invested in PGI in Chile during the past three decades could have generated 11.5 dollars of government tax revenues from the mining industry (in terms of its NPV), with an IRR of around 21%. These results are in accordance with comparable studies abroad, but they should be taken carefully due to methodological restrictions of the study. These indicators are positive in almost all the scenarios considered in the study, despite that they show a wide range of results. Similar outcomes are obtained for the National Geological Program when different scenarios are evaluated.

1. Introduction

Despite the size of the Chilean mining industry and its relevance for the local economy, the available public geoscience information (PGI) is deficient in terms of coverage and updating. By 2012 only 30% of the country has modern and detailed geological maps at a scale of 1:100,000 (Schwarz et al., 2012). According to Jara and Cantallopts (2008), the main problems related to this topic in the country are: a) deficiency in coverage and updating of information; b) limitations to access and use of the available information; c) the need for new tools to acquire and analyze data; and d) the lack of new/advanced types of information.

To remedy this situation, in 2011 the Ministry of Mining through the National Geological and Mining Service (Sernageomin, by its Spanish acronym) started a National Geological Program (NGP). This program is aimed to reduce the gap between supply and demand for geoscience information in the country. An original ambitious goal was to achieve a basic geology, geochemistry and geophysics cartographic coverage for most of the territory, over a period of 10 years (2011–2020) (Espinoza, 2015; Sernageomin, 2017). Currently the agency is provided with 6 million dollars per year for its execution, which corresponds to about half of what was initially requested to the central government by the service. The reduction of available resources, combined with other difficulties such as a shortage of experienced professionals at the time the program started, have generated a significant delay in the original plan. Therefore, currently it is estimated that the NGP will take at least 50–100% more time than initially estimated (Muñoz, 2013; Espinoza, 2016).

The aim of this study is to determine the direct economic return of PGI provided by the Chilean state, in terms of the tax revenues collected from the mining industry. To do so, the study applies a methodology based on multiplier effect (benefit-cost) ratios through the steps of the PGI value chain (structured stages of development modelling) and a probabilistic discounted cash flow model (Monte Carlo simulations) to evaluate the direct economic impacts of different scenarios for the NGP that is underway in the country.

Quantifying the benefits associated to PGI should contribute to the public debate, to the promotion of policies that could foster the country's geological potential and its mining competitiveness and to support the decisions of the competent authorities in Chile (Jara et al., 2008). Finally, it should open opportunities for future research with focus on the allocation of public funds related to geological programs.

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The article is structured as follows. Section 2 addresses the role of PGI in enhancing mineral exploration and mining, reviewing the economic effect that this kind of initiatives could generate. Section 3 presents the main aspects of the methodology and the databases to evaluate the Chilean case. In Section 4 the main results for historical analysis and the National Geological Program are presented. The discussion of the outcomes and some recommendations from the research are found in Section 5.

2. Public geoscience information and its stimulus to mineral exploration and mining activities

Several studies (Herfindahl and Kneese, 1974; Bernknopf et al., 1997; Hogan, 2003) notes that PGI meets some of the main characteristics of a public good[1] (quasi-public good), since its use is not rival nor exclusive. It can advance useful information in areas of public interest such as land management, infrastructure planning and development and natural resources assessments (Ovadia, 2007; Castelein et al., 2010; Häggquist and Söderholm, 2015).

Regarding the mineral exploration and mining industry, PGI is valuable because it reduces the risk of greenfield activities (and in some cases in brownfield exploration), cuts expensive re-acquisition of data, catalyzes refinement of geological knowledge and decreases environmental impacts of exploration programs. Thus, it improves the efficacy and efficiency of mineral exploration and maintains the competitive edge of mining jurisdictions (The Parliament of the Commonwealth of Australia, 2003). As a result, PGI mitigates the three main challenges which differentiate this activity from other economic sectors: specific locations, long-term returns and high-risk investment levels (Eggert, 1987; Tilton et al., 1988).

There are three main factors that make it difficult to assess the effects of PGI (Duke, 2010; Häggquist and Söderholm, 2015): it is virtually impossible to identify all users of the information; impacts are long-lived as it can influence exploration decisions for more than 20 years (in addition, mining development can last from 10 to 20 years, or even more); and it is difficult to evaluate the exact contribution of PGI, since in the decision-making process it is combined with other factors that influence mineral exploration success (Fogarty and Sagerer, 2016).[2]

Given these limitations, a useful approach to measure the effects of government PGI programs is to run a step-by-step/benefit-cost evaluation process (Input-based assessment; Häggquist and Söderholm, 2015), which shows progress from the initial activities of PGI to the achievement of government plan objectives (Fig. 1).

According to this method, the initial effect of PGI is the stimulus of private efforts in exploration. Geoscience Australia estimates that every dollar invested by the state in PGI generate five dollars in private exploration expenditures (The Parliament of the Commonwealth of Australia, 2003). The same source indicates that the Government of South Australia considers that this factor has a multiplier effect from three to five times the public investment in basic information. The Queensland Government raises this factor up to 15, according to the experiences in its territory. In the case of Canada, the Government of Ontario estimates that every dollar invested in PGI generates between two to five dollars in terms of exploration by private entities (Fyon et al., 2002). Based on 13 case studies in Australia and Canada, a work commissioned by the Canadian government concluded that every million-dollar invested by these governments in such basic information stimulated private exploration expenditures for roughly five million dollars (Boulton, 1999).

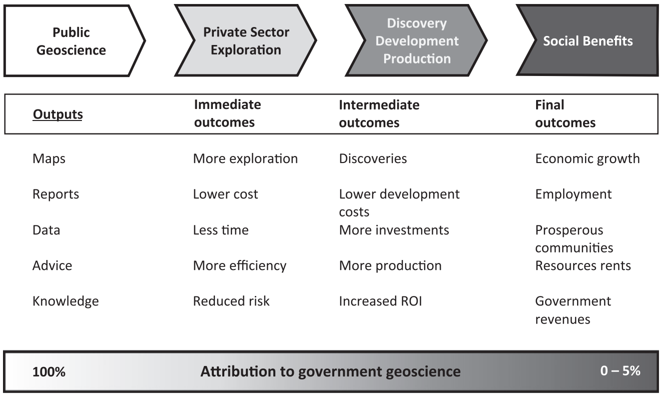

Fig. 1. PGI value chain and its intermediate and final outcomes.
Modified from Duke (2010).

In a report commissioned by the Prospectors and Developers Association of Canada (PDAC) the multiplier ratios vary greatly, from a minimum of 0.83 to a maximum of 19 (Duke, 2010).[3] However, the conclusion of the author is that it is reasonable to use a factor of five as a rule of thumb. Nevertheless, the evaluators should understand the limitations and specific aspects of the case to be analyzed, such as the period and scope of the PGI plans. An alternative to these ex-post analysis is the approach of Bernknopf et al. (2007), based on mineral prospectivity evaluations and economic modelling. Using these tools, they evaluate the future impact of a second generation PGI program in the Baffin Islands, showing a multiplier effect between 1.2 and 8.2, consistent with other retrospective assessments.

Regarding intermediate results, mineral exploration identifies deposits that may become attractive to be developed and exploited in the future. While data on the direct impact of PGI on the discovery and development of projects is scarce, there is enough information about the effects of private exploration on mining development stages. A study on copper exploration in the Central Andes of Argentina, Chile and Peru (Cabello, 2004) shows that between 1969 and 2001 every dollar spent on exploration generated 6.1 dollars associated to mining development and an additional 7.8 dollars in future investments (4.5 and 5 dollars in the case of Chile; Cabello, 2006). Similarly, every dollar spent on exploration caused, at the time of the study, 14.9 dollars in mineral production and 226 dollars on in-situ resources (23 and 125 dollars in the case of Chile; Cabello, 2006).

Closing these series of results are the so called final effects of PGI, related to its contribution to economic development and society's welfare. Duke (2010) indicates that a value commonly attributable to PGI on this matter is between one and five percent of mineral production, but it easily could be more than that. Swan (1997) proposes to assess the results of state programs in terms of their contribution to the value of mineral production. Therefore, PGI is considered as a production factor whose contribution is proportional to its cost. Alternatively, Scott et al. (2002) run an economic model to evaluate royalty and tax increments due to PGI improvement plans (which leads to higher discovery rates, based on mineral potential assessments), incorporating uncertainty and risk. They conclude that the increase in royalties and taxes is equivalent to a benefit-cost ratio of 4.7–6.2:1 (in terms of net present value) with an IRR of 23–78%, depending on the reinvestment scenario considered. Finally, in a recent study Fogarty and Sagerer (2016) assess the government returns from PGI and other exploration subsidies in Western Australia. Through a structured stages of development modelling approach, time-series analysis and Monte Carlo

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[1] They are goods that their use is not rival nor exclusive; i.e., it is not possible to prevent a person uses a public good, and its use by one does not reduce its use by others (Samuelson, 1954; Mankiw, 2015).

[2] As noted by Fogarty and Sagerer (2016), other factors such as new deposit discoveries, economic cycles, metal price variations, tax incentives and mining and general regulation changes cannot be completely isolated when evaluating PGI contribution to mineral exploration success.

[3] It includes some of the previous references plus others mainly from Australia, Canada and a couple of PGI plans in countries such as Bolivia and Zimbabwe.

simulations, they show that between 1990 and 2014 the subsidies to exploration (PGI and direct drilling support) had a benefit-cost ratio that moves from 5.2 to 9.0 depending on the discounted rate of choice.

3. Methodology and datasets to assess the government return from PGI in Chile

3.1. General methodology

In Chile, most of the data on PGI investments, discovery rates, mineral resources and mining reserves is not publicly available, is scarce or is not reliable. Moreover, there are few government attempts to quantify mineral potential of the country's territory. Therefore, it is hard to apply robust/state-of-the-art methodologies, based on benefit-cost ratios as used in Scott et al. (2002) or Fogarty and Sagerer (2016) to estimate the direct economic return of PGI programs. This study attempts to overcome this problem by relating the existing information of the logical sequence in Fig. 1 and some aspects of the methodologies proposed in those studies.

Scott et al. (2002) ran a two-step approach to assess the direct economic return of government regional geoscience programs. The first step is to quantify the impact of new geoscientific data on private exploration and on the number and characteristics of undiscovered deposits. It is achieved applying statistical analysis of revealed and declared preferences of exploration companies, and by quantitative resource assessments and prospectivity modelling of the territory involved in the study. Then, a benefit-cost analysis based on discounted cash flow models, sensitivity tests and risk assessment (Monte Carlo simulations) is developed for the results of the first stage. Thus, a probability distribution of NPV and IRR of the PGI investment is obtained.

Fogarty and Sagerer (2016) also uses a two-step methodology but sustained on different tools. First, they estimate the response of exploration activity to PGI initiatives by a time-series model using historical data from Western Australia. The second step is a benefit-cost analysis based on multiplier ratios and Monte Carlo simulations of discovered deposits. The authors apply stage one results to calculate private exploration incentivized by PGI programs, and using historical data they estimate the number and characteristics of the expected discoveries. Then, a probabilistic discount cash flow model is used to evaluate the potential profitability and the return to government. The result is a distribution of the benefit-cost ratio in terms of its net present value.

Since there is no reliable information regarding historical PGI expenditures, mineral resources and mining reserves in Chile, step one in Fogarty and Sagerer (2016) methodology could not be applied. The same occurs with Scott et al. (2002) first stage approach.[4] Hence, to replicate Scott et al. (2002) methodology in Chile implies to develop a comprehensive assessment of the mineral resources of the country, which is beyond the scope of this work.

Therefore, multiplier effect (benefit-cost) ratios approach based on international data is used to calculate the private exploration response to PGI programs. The same problem is found when trying to apply the second step in Fogarty and Sagerer (2016). Good information could be found regarding successful discovery and developed mines in Chile. However, data on marginal or non-economic deposits is scarce or not publicly available. Thus, it is preferred to use the input-based methodology (Häggquist and Söderholm, 2015) relating historical private exploration expenditures, mine development investments, mineral production and tax revenues from mining activities, incorporating uncertainty and risk through a probabilistic discount cash flow model.

Consequently, the methodology used in this study is similar to that applied by Fogarty and Sagerer (2016) in its second part. It uses structured stages of development modelling approach (multiplier effect ratios) for the PGI value chain, combined with Monte Carlo simulations.

3.2. Databases and the PGI value chain in Chile

3.2.1. The PGI value chain in Chile

The PGI value chain starts with the generation and release of geoscientific information and knowledge by the public office responsible of this task, and ends when the social benefits of its use are materialized. An unknown number of processes are involved in between. Hence, multiple alternatives could be constructed to model the value chain.

The simplest model could directly relate government investments in PGI and the tax revenues from mining activity using a single multiplier effect ratio. However, this approach has two main problems: a great number of variables, independent of PGI efforts, affect the government revenues from mining; and second, government returns from PGI usually takes several decades to materialize. Thus, the election of values and timing distributions does not incorporate specificities and changes in the intermediate stages and could bias the results of the analysis. Conversely, it is hard to find adequate information to pursue highly detailed schemes that includes most of the variables affecting the PGI value chain.

This work defines three major intermediate stages for the PGI value chain, together with the initial and final steps: 1) mineral exploration expenditures; 2) mining project development investments; and 3) mineral production from mine operations. Each of these stages have specific values/timing probability distribution functions and there are good public datasets for the case of Chile (based largely on historical series). The only exception is the initial multiplier ratio that relates PGI investments and private exploration efforts.

As a result, the framework for the evaluation includes the five stages defined previously and the four intermediate processes that relate one stage to the next (Fig. A1, Appendix A). The former are modeled by two variables and their probability distribution functions: VD_i, which shows how the value of the multiplier ratio is distributed in different years (i.e. the percentage of money to be invested in every particular year of the stage); and SL_i, the length of each stage. The latter are also represented by two variables: MR_j, the multiplier effect ratio between two consecutive stages; and LT_j, which represents the time needed to start the materialization of the effect (lag time between stages).

3.2.2. Attributes of the stages of the PGI value chain in Chile

Based on historical datasets, scientific articles, congress/seminar presentations and expert opinions, triangular distributions were fitted for the length of each step. The PGI process (Stage A) is considered to be instantaneous ($SL_A = 0$). This is not true, since the investment to generate and release the associated products could take from a couple of months to several years. However, for the purposes of this research it is assumed that all the funds are invested in the year of the products publication.

The duration of the exploration stage (Stage B) is defined as the time between the beginning of private search for new deposits and the start of a project development phase (SL_B). A minimum of five years, an average of seven years and a maximum of 10 years is assumed, based on historical exploration efforts in Chile and abroad (Schodde, 2011, 2014; Fréraut, 2016). Project development starts at the end of the exploration stage and runs until the start of mineral production (Stage C). Depending on the project size and location, this stage could last from one to five years, with a mean of three years (SL_C). These values are obtained from mining projects developed in Chile and from expert's opinions (Sykes, 2013; Wood Mackenzie, 2015a; Jennings and Schodde, 2016). Mineral production (Stage D) begins with operation commissioning and ends with the last year of its useful life, covering a period between 10 and 20 years with an average of 15 years (SL_D). These are

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[4] Cunningham et al. (2008) is the only publicly known quantitative resource assessment study of the Chilean territory, but only comprises porphyry copper deposits.

conservative values for greenfield projects in Chile and consider the average mine life of operations in the country, excluding super giant deposits such as Collahuasi, Chuquicamata, Escondida, Los Pelambres, Río Blanco-Los Bronces cluster and El Teniente (Guzmán, 2013; Wood Mackenzie, 2015b). Nevertheless, the discounted cash flow methodology used here implies that money flows beyond this span of time have a small impact on the economic results.

Government tax revenue (Stage E) is the final step in the study. The length of this stage follows the same guidelines and values of the mineral production phase, since taxation depends on the production and profits for each year. However, the model considers a capital payback period when mines pay only an additional tax (a specific tax for mining in Chile) but not the general rent taxes. This period of virtually non-tax flows is considered to have a triangular distribution with a minimum of three, an average of five and a maximum of seven years. The combination of both triangular distributions generates the tax revenues length distribution (SL_E).

Regarding the value distribution of the investment (VD_i), it depends on the duration of each stage. In other words, the value generation captured by the multiplier effect ratios are not instantaneous nor homogeneous, but has a period in which it materializes. For example, the value added generated during the mineral production is distributed throughout the whole mine life. It usually has a specific shape that involves increasing cash flows at the beginning of the operation, reaching a peak of production and then declining as the deposit resources are depleted and the operation ages. Under this logic, each multiplier ratio has associated a distribution schedule. This work considers three different scenarios, related to the parameters of the length's triangular distributions: a minimum (VD_i^{min}), a medium (VD_i^{mid}) and a maximum (VD_i^{max}) length scenarios. The length of the latter stage included in the associated multiplier ratio determines which of the scenarios is applied.

The parameters for VD_i and SL_i distributions for each case considered in this study are presented in Fig. A1 in Appendix A.

3.2.3. The in-between processes in the PGI value chain in Chile: multiplier effect ratios and lag times between stages

The previous section describes the general assumptions for each of the stages involved in the PGI value chain in Chile. This information establishes the basis to obtain the variables that define the in-between processes: the multiplier effect ratios (MRj) and the lag times between stages (LT_j).

MR_0 relates public PGI investment and private exploration expenditures. There are no studies about the effects of PGI on mineral exploration in Chile, thus this ratio is estimated based on more than 15 international experiences that were compiled by the PDAC report (Exhibit 14; Duke, 2010). The available data follows a lognormal distribution with a mean of 5.12 and a standard deviation of 3.86 (excluding higher and lower values). Since it takes some time to internalize the information and to generate new/improved exploration models, there is a lag between the release of the PGI products and the start of the exploration activities stimulated by them. This lag time (LG_0) follows a triangular distribution with a mean of three, a minimum of two and a maximum of five years. Even though this variable is not used to calculate MR_0, it affects the timing of cash flows in the economic model.

Historical information is used to calculate the other multiplier effect ratios in the value chain: MR_1 = (mining development investments / private exploration expenditures); MR_2 = (mineral production / mining development investments); and MR_3 = (fiscal revenues / mineral production). Each of these factors is a ratio between the economic values (expenditures, investments, value added or tax incomes, all in terms of US dollars) involved in two consecutive stages, and represents the value generated/transferred when the process advances from one stage to the next.

However, two assumptions must be made. First, these ratios are time dependent since they should reflect the time lag between the two stages. This interval is a function of the former stage duration involved in the particular ratio discussed in the previous section (except for MR_3). Additionally, historical series tend to show high volatility and cyclical patterns. Thus, moving average of each datasets are used to smooth year-to-year fluctuations to better reflect the trends through the whole period of study. Moreover, taking long-term moving averages allows to avoid ratios inflation in the last years of the study due to the commodities super-cycle (see Appendix B). Therefore, dividing the moving average series of each stage in the ratio lagged by a specific interval, it is possible to obtain the probability distribution function of the multiplier effect ratio for this fixed lag time. As a result, it is necessary to calculate the ratios for every length of the stage that determines the lag time (the former one). Accordingly, MR_1 includes six alternatives, one for each lag from five to ten years. MR_2 has five options and MR_3 only one, because it does not involve a lag time between production and tax revenues.

To calculate MR_1, exploration expenditures and mining investments series are required. PGI has relevant impacts primarily on basic and advanced greenfield mineral exploration (grassroots and late stage/feasibility exploration, accordingly to S&P Global Market Intelligence classification[5]), but small or non-effect on minesite activities. Three studies from the Chilean Copper Commission (Cochilco by its Spanish acronym; Pérez et al., 2005; Schwartz et al., 2012; Rojas et al., 2016) provide statistics on exploration expenditures in Chile (in nominal dollars) from 1993 to 2013, based on Metals Economics Group data (currently part of S&P Global Market Intelligence). Prior to this date, data is available in Mackenzie et al. (1995). Fig. 2A shows the non-ferrous, non-minesite mineral exploration expenditures in Chile from 1970 to 2012, which was used to calculate MR_1.

Large-scale mining investment in Chile, which accounts for more than 95% of total mining investment in the country, can be separated into two major components: public related, including projects related to the Corporación Chilena del Cobre and Empresa Nacional de Minería (Codelco and Enami by its Spanish acronyms; state-owned mining companies); and private investments, mainly related to foreign direct investments. Both series are publicly available in Cochilco's yearbooks from 1976 to 2012 (Cochilco, 1995–2012). Prior to that date, this study estimates are based on historical information. However, a small change should be included to avoid double-counting of exploration expenditures, since the original investment data includes them. Fig. 2B presents the mining development investment series used to calculate MR_1 and MR_2.

Mineral production allows to evaluate some of the final effects of PGI, such as tax revenues, exports and other direct economic impacts from the industry. Information of mineral production is based on gross domestic product series from the mining sector in Chile (mining GDP), which is obtained from two different sources. From 1970–1985 it is found in a study by the Pontificia Universidad Católica de Chile (Braun-Llona et al., 2000). After that year and until 2012 the series from the Central Bank of Chile (2017) are used. This data is expressed in nominal Chilean pesos, which are converted to nominal dollars with the local exchange rate of each year. Fig. 2C shows the mining GDP series used to calculate MR_2 and MR_3.

Finally, government tax revenue series is obtained from two sources: Braun-Llona et al. (2000) prior to 1996; and from Cochilco's annual yearbooks (Cochilco, 1995–2012), which includes both private and state-owned companies' contributions to the Chilean Treasury, up to the present. Private sector data is based on tax payments from the 10 largest private-owned operations in the country (GMP10 for its Spanish acronym), a group that represents more than 90% of private production in the country. Tax revenues by state companies consider total flows from Codelco and Enami. Fig. 2D present the mining government

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[5] S&P Global defines three exploration stages: grassroots, late stage/feasibility and minesite.

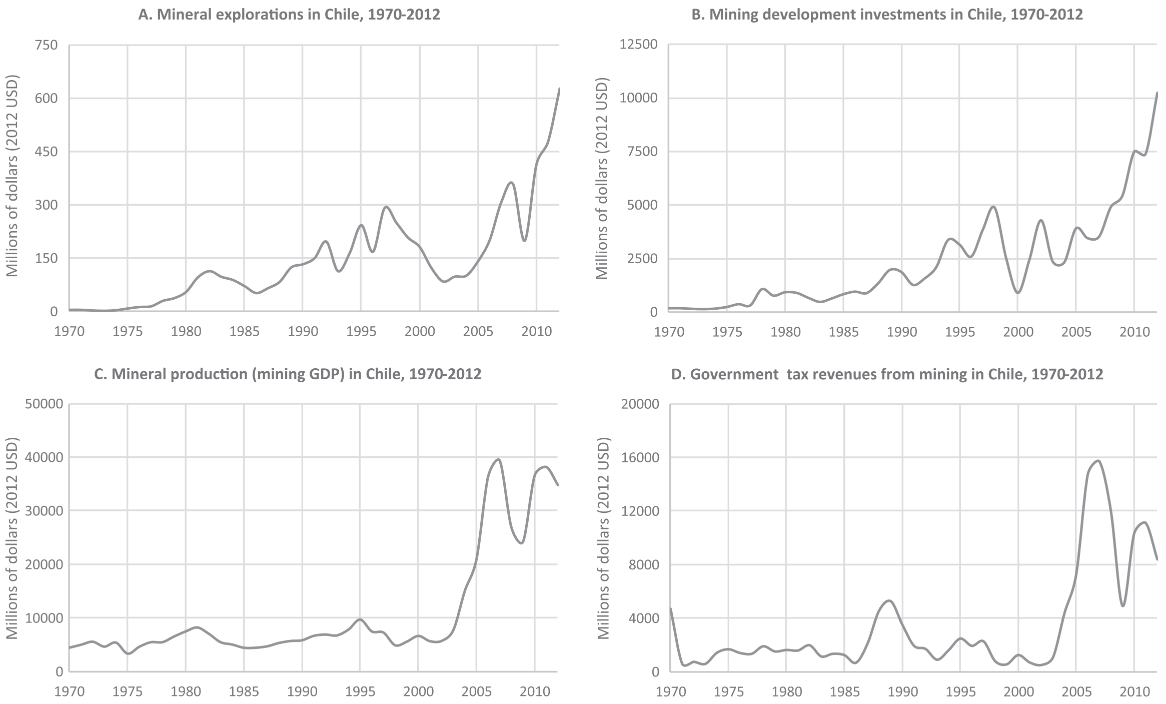

Fig. 2. Historical datasets used to calculate MRj in this study. a) Non-ferrous, non-minesite mineral exploration expenditures in Chile 1970–2012 (modified from: Mackenzie et al., 1995; Pérez et al., 2005; Schwarz et al., 2012; Rojas et al., 2016). b) Mining development investments in Chile 1970–2012 (modified from: this study estimates; Cochilco, 1995–2012). c) Mineral production in Chile 1970–2012 (modified from: Braun-Llona et al., 2000; Central Bank of Chile, 2017). d) Government tax revenues from mining in Chile 1970–2012 (modified from: Braun-Llona et al., 2000; Cochilco, 1995–2012).

revenues from the mining activity used to calculate MR_3.

Exploration expenditures and mining investments are expressed in real US dollars of 2012 using the Producer Price Index All Commodities (Bureau of Labor Statistics, 2013). Mineral production and tax flows are deflated using the Consumer Price Index developed at the Oregon State University (2013).

As previously explained, several multiplier effects ratios can be obtained when the lag time is changed (six for MR_1, five for MR_2 and one for MR_3; Table 1). To simplify the discussion, the results associated with moving average of 10 years for MR_1 and MR_2 and five years for MR_3 are presented here. The related moving average time-series charts for MR_1, MR_2 and MR_3 and other moving average combination values can be found in Appendix B.

The parameters for LT_j and MR_j distributions for each case considered in this study are presented in Fig. A1 in Appendix A.

Table 1
Multiplier effect ratios and lag times between stages of the PGI value chain in Chile calculated in this study.

MR_j	LT_j	Distribution	Parameters	
			Mean	Std. Dev.
MR_0	–	Lognormal	5.12	3.86
MR_1	5 y	Normal	20.7	4.68
	6 y	Normal	21.46	4.75
	7 y	Lognormal	22.27	4.72
	8 y	Normal	23.36	4.93
	9 y	Normal	24.75	5.33
	10 y	Normal	26.35	5.71
MR_2	1 y	Normal	4.28	1.74
	2 y	Normal	4.59	1.91
	3 y	Lognormal	4.98	2.57
	4 y	Lognormal	5.17	2.08
	5 y	Normal	5.43	1.84
MR_3	–	Normal	0.26	0.08

4. Cases of analysis and results

4.1. General considerations

To assess the direct economic return to government, a discounted cash flow model is constructed. It allows to quantify the final effect of PGI programs in terms of their net present value (NPV), internal rate of return (IRR) and profitability index (i.e. the ratio between the net present value and the investment - NPV/I). Moreover, this methodology permits to calculate a benefit-cost ratio through the whole PGI value chain.

However, some general considerations should be noted. The applied discount rate is 10%, which is commonly used in project assessments in the mining industry in Chile.[6] This discount rate is slightly higher than the range used in Scott et al. (2002): 4–6%. It is also higher than those used in Fogarty and Sagerer (2016), which use three scenarios: 5%, 7% and 9%. Regarding the timeframe of the evaluation, it considers the time span until the last period in which tax flows are generated. Hence, the number of periods in the model is specific for each of the scenarios that are analyzed.

Finally, a flexible model is considered to incorporate variables and their probability distributions to generate different scenarios. To incorporate risk and uncertainty into the model, Monte Carlo simulations approach (1000 runs for each scenario) and sensitivity analysis are incorporated (Glasserman, 2003).

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[6] An alternative is to use the government discount rate for social investments, which in Chile is 6%. This is below the 10% rate used here. Therefore, the results presented are conservative if they were used to evaluate the NGP as a public policy of the Chilean government. However, due to the highly variable and long term effects of PGI initiatives (i.e. associated risks), it seems reasonable to think in a discount rate higher than those used to evaluate traditional social programs.

4.2. Historical direct economic return to government from PGI investment in Chile

Based on historical information, the results of the model considering that 1 million US dollars could have been invested in new PGI in Chile are shown in this subsection. First, a risk-based case is presented. Then, the outcomes of the sensitivity analysis for the most relevant scenarios.

The risk-based case scenario considers SL_i, LT_j and MR_j variables represented by their probability distribution functions and VD_i in their expected values (VD_i^{mid}). Figs. C1 and C2 in the Appendix C shows the risk-based case NPV (benefit-cost ratio) and IRR probability distributions for the historical investment in PGI by the Chilean government. The probability distribution results for the other two alternatives for VD_i (VD_i^{min} and VD_i^{max}) could be found in Gildemeister's thesis (Gildemeister, 2014) or requested from the authors.

The historical investments in PGI by the Chilean government shows a benefit-cost ratio higher than 1.0 for more than 90% of the simulations, with a mean value of 11.5 and extreme values (95% confidence level) around 0.1 and 47. It is important to notice the distribution function of this economic indicator: it follows a kind of lognormal distribution, probably related to MR_0 behavior. On the other hand, the IRR is around 20%, with extreme values (95% confidence level) near 6% and 30% and a plausible normal distribution. The average NPV and IRR and their confidence levels for the three alternatives (VD_i^{min}, VD_i^{mid} and VD_i^{max}) are detailed in Table 2.

To complement these results, a sensitivity analysis regarding the multiplier effect ratios and stages lengths is run. Table 3 is a two-entrance matrix relating percentiles 10, 50 and 90 for the multiplier ratios (MR_j) and the maximum, minimum and mean values for the duration of the stages (SL_i), showing the NPV/IRR of te PGI investment. In this table, the value distribution variable is set in its mid scenario (VD_i^{mid}).

From this table, it could be seen that only the scenario when both variables (MR_j and SL_i) are on their worst cases the NPV is negative. These results reinforce the appreciation that government investment should have a positive direct economic return.

Finally, the individual effect of each variable in the model is analyzed in Fig. 3. This chart presents the benefit-cost ratios (NPV) for border conditions of each variable: MR_j, SL_i and VD_i (IRR results in Appendix D). The analysis considers that all other variables remain in their mean values. The central case (MR_j^{50}; SL_i^{mid}; VD_i^{mid}) and the lower (MR_j^{P10}; SL_i^{max}; VD_i^{max}) and upper (MR_j^{P90}; SL_i^{min}; VD_i^{min}) boundaries are included as references.

As can be seen, none of the individual variables solely can generate a negative scenario (negative NPV). Moreover, the only variable that has a relevant independent effect MR_0. This multiplier ratio can generate a 7x range for the benefit-cost ratio, from a value slightly over 3.5 to more than 22.

4.3. Direct economic return to government from the National Geological Program in Chile

The National Geological Program (NGP) was proposed at the end of the past decade by Sernageomin and it started in 2011. The aim of this government program is to provide most of the country with basic updated geoscience knowledge and related databases to comply with diverse society requirements: land management, natural disasters control programs, natural resources assessments and private activities, among others (Muñoz, 2013). It includes three scientific areas which main products are: regional geology maps at 1:100.000 scale; aerogeophysics (magnetic and gamma radiation) maps at 1:100.000 scale; and stream sediments geochemistry (61 elements) maps at 1:250.000 scale. The original plan to complete the project considered a total budget of 200 million US dollar for a 10 years term, from 2010 to 2020; i.e., 20 million US dollar per annum (in real US dollar of 2010).

Table 2
Monte Carlo simulation results for the risk-based cases.

Scenarios	NPV (USD)		IRR (%)	
	Mean	Range at 95% conf. level	Mean	Range at 95% conf. level
VD_i^{min}	12.0	−0.02 to 48.2	22.0%	6% to 32%
VD_i^{mid}	11.5	0.07 to 47.0	20.6%	6% to 30%
VD_i^{max}	8.4	−0.24 to 31.2	18.4%	6% to 27%

Table 3
Sensitivity analysis for the multiplier effect ratios and stages lengths.

Scenarios	MR_j (P_{10})		MR_j (P_{50})		MR_j (P_{90})	
	NPV (USD)	IRR (%)	NPV (USD)	IRR (%)	VPN (USD)	IRR (%)
SL_i^{min}	0.4	12.3%	15.7	31.6%	109.4	50.5%
SL_i^{mid}	0.1	10.6%	8.6	21.8%	75.6	34.3%
SL_i^{max}	−0.5	8.7%	4.0	16.1%	29.9	23.4%

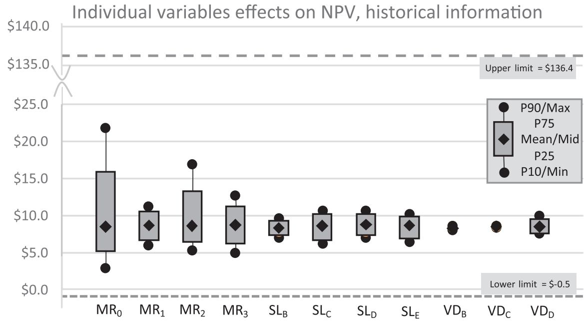

Fig. 3. NPV (benefit-cost) results of individual variables effects.

Notwithstanding the public support to this project from the whole political spectrum, it has suffered substantial modifications due primarily to annual budgets limitations and to other resources restrictions by Sernageomin. Therefore, it is of interest of this research to evaluate the consequences of these changes in terms of the government direct return from the mining activities that could be incentivized by this PGI program. To do so, four scenarios are analyzed. The key economic indicators to evaluate the direct economic return to government are, as already mentioned above, the NPV, IRR and NPV/I of the PGI investment.

The first scenario for the NGP is its original plan. It considers an investment of 20 million US dollars per year for 10 years. The second is a neutral case, which maintain the total budget of 200 million US dollars and the products to be generated, but extend the lifetime of the project to 2030; the annual budget for the first 10 years is 11 million US dollars, similar to the funds received from the government until 2015, and then it falls to 9 million US dollars per year. Under this situation a 90% of the proposed products (maps) should be generated. The third scenario is a pessimistic one. This alternative assumes that current budgets continue until 2020 and the cartography coverage accomplishes only around 60% of the territory, with the total investment reaching 110 million US dollars. Finally, an optimistic case is considered. It supposes that current budgets (11 million US dollars) are sustained for a 20 years period, which should allow to complete the original plan. In all the cases, the annual investments are on 2010 US dollars. However, for model purposes they are deflated using the Producer Price Index All Commodities (Bureau of Labor Statistics, 2013). Moreover, since personnel salaries and field-based activities are the main costs of PGI programs, a constant exchange rate of 600 CLP/USD (general consensus estimate) and a local annual inflation rate of 3% (which is the Chilean Central Bank mid- to long-term goal) are considered to carry forward NGP investments.

Table 4
NPV, IRR and NPV/I results for the NGP scenarios.

Scenarios	NPV (USD mill.)		IRR (%)		NPV/I
	Mean	Range at 95% conf. level	Mean	Range at 95% conf. level	Mean
Original	2133	0.9 to 8599	22.4%	6% to 33%	14.1
Pessimistic	1088	6.4 to 4478	22.1%	6% to 32%	13.1
Neutral	1616	15.3 to 6608	22.2%	6% to 32%	13.6
Optimistic	1837	17.6 to 8159	22.4%	6% to 33%	14.0

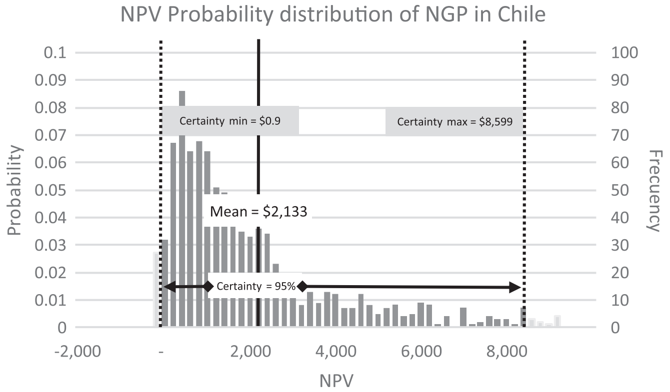

Fig. 4. NPV probability distribution function for the original case of the NGP.

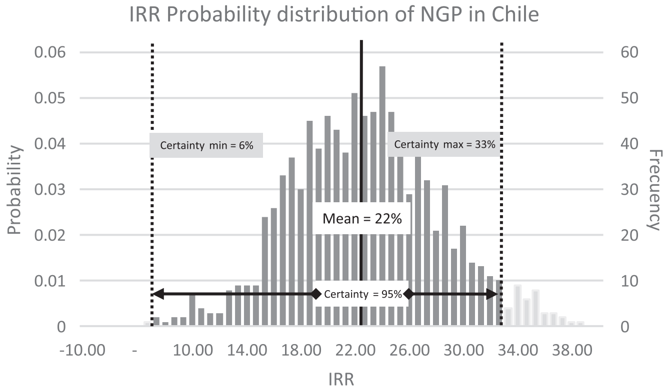

Fig. 5. IRR probability distribution function for the original case of the NGP.

The overall results of the direct economic evaluation for the proposed scenarios are presented in this subsection. These include results from NPV and IRR mean values for each scenario, along with their associated NPV/I ratio. In addition, a range value within 80% and 95% confidence levels are given for these primary economic indicators.(Table 4)

NPV and IRR probability distribution functions for each scenario could be found in Gildemeister's thesis (Gildemeister, 2014) or requested from the authors. The results for the original NGP are presented in Figs. 4 and 5.

The original case of the NGP shows a benefit-cost ratio (NPV/I) of 14.1, with a mean value of 2133 million US dollars and a distribution function following a kind of lognormal distribution. On the other hand, the IRR is around 22% and its probability distribution function consistent with a normal distribution.

5. Discussion and recommendations

The relevance of mineral exploration to sustain the continuity of mining operations and to boost industry growth has led to a series of studies about the factors that contribute to its development (Jara, 2017). In this context, PGI has shown to be essential to foster exploration efforts and increasing mining activity. Chile has a recognized geological potential, but its available PGI was poor, both in updating and coverage, if compared to other relevant mining jurisdictions. Although this implied a competitive disadvantage, it also represented an opportunity to foster exploration activities and to increase future government revenues from mining. This is one of the reasons why the Chilean government launched its National Geological Program in 2011.

The results of this study are the first attempt to assess the direct economic return to government from PGI programs in Chile. The central case for the historical available information shows that every dollar invested in PGI could generate 11.5 dollars of tax revenues (in terms of its net present value). It represents a 20% internal rate of return over the investment. The probabilistic analysis, with a confidence level of 95%, yields a range between 0.1 and 47 for this benefit-cost ratio, and an IRR amid 6–30%. While these results show a high variability, their distribution indicate a positive assessment for PGI investments in Chile.

The sensitivity analysis shows that there is a chance to have returns lower than the investment ($NPV/I < 1$) or even negative results ($NPV < 0$). However, the probability of this happening is minimum. This situation occurs only if all the variables included in the analysis are in their worst case or near them. Any other combination gives positives outcomes. Regarding the individual impact of each variable, the most relevant ones are the multiplier effect ratios (MR_j). They define the value generation/transference between one step of the PGI value chain to the next.

Amongst the multiplier effect ratios, the relationship between PGI investments and private exploration efforts (MR_0) has the greatest impact. Given the fact that this is the only variable based on international experiences instead of specific data for Chile, it would be of great interest for future research to estimate its probability distribution based on local characteristics/information. Similar approaches as those in Scott et al. (2002) and Fogarty and Sagerer (2016) would be valuable and could contribute to corroborate the results of this study, but information quality and availability should be take it into consideration.

The analysis of the NGP shows that this initiative could be a good public policy in terms of its direct economic return to the government. Though the original plan of the Chilean Government generates higher returns compared to all other scenarios, the results for the alternatives reinforces the assumption that special attention must be paid in the materialization of this kind of projects, in terms of schedule and budget.

The results of this research are comparable only to two known studies published in the academic literature. Scott et al. (2002) conclude that every dollar invested on PGI in the State of Queensland, Australia could generate between 3.8 and 5.8 dollars in tax revenues, with an IRR of the investment of 23%. Second, Fogarty and Sagerer (2016) report an average return to government that varies from 5.2 to 9.0 in Western Australia. The higher benefit-cost ratio for the case of Chile could be explained by the extraordinary copper exploration results during the 1980s and 1990s (Leveille and Doggett, 2006) and by the low capital costs and operating expenditures associated to mine construction and operation in the 1990s and 2000s (Wood Mackenzie, 2015a). As a result, a 1.5x to 2.0x effect on the total benefit-cost ratio do not seem unreasonable. Moreover, the NPV results for the NGP scenarios (1050 to 2150 million dollar) represent the tax revenues that the Chilean government currently receive during the minelife of only one average operation (an operation producing 200 thousand tons of copper per year). Nevertheless, due to the shortcomings identified in the data and methodology used in this research, a cautionary approach should be recommended. The results only show that PGI programs in Chile should have a positive direct return to government, with benefit-cost ratios similar to those reported in other international mining jurisdictions; and extreme values obtained in this research are probably associated to: the mining boom of the 80 s and 90 s in Chile, which led the country to represent more than 35% of the world copper production; and to the limitations of the study.

Regarding the methodology, it is important to remark that it contains three important assumptions: (1) the relationship between one multiplier effect ratio and the next is only associated to the lag time, but the value and probability distribution function of the former do not affect the value of the latter (i.e. the value of calculated multiplier ratios are independently distributed from each other); (2) the multiplier effect ratios are average relationships between variables in two consecutive stages, instead of marginal effects among them; and (3) this ratios reflect increments of activity (investment, production or tax payments) in each stage due to the generation and release of new PGI; but the methodology considers no changes in other variables that could affect the activity in each stage of the PGI value chain.

The first assumption should imply only a minor effect (or not effect at all) on the results of the central cases of this study. However, the consequence on boundary scenarios could be substantial, since lower (or higher) multiplier ratios at the beginning of the PGI value chain may possible be replicated or even augmented downstream. The second statement is required because average series are the only available data to work on. Moreover, they could be a good proxy for current marginal relationships if it is assumed that Chile is not already at a point on the decreasing resources quality/quantity on its "undiscovered resources curve". If this is the case, marginal discovery cost of new resources should be similar to the average exploration cost of discoveries in recent years. The same applies for mining project developments, mineral production and mining tax revenues. Finally, the omitted variable biases could also generate some concerns. The multiplier effect ratios MR_j calculated here assume that nothing else affects the numerators of the ratios other than the denominators themselves, which in a general perspective is not true. However, if these ratios only reflect the exploration, mining investment, mineral production and mining taxes incentivized by the new PGI, they could be viewed as increments of these activities. If the rest of the variables that affect the numerators do not change (i.e. if the new PGI is evaluated in a ceteris paribus scenario), the impact of these increments should have the same effect (the average value) of any other non-specified effect in each stage of the PGI value chain. If these assumptions do not apply in a particular case, they could substantially affect the results of this study. This is the reason why this study is based on moving averages of long-term series. Nevertheless, a preliminary approach to fully address these issues might be to construct a simultaneous-equation, time-series econometric model to estimate each value as a function of the former one in the PGI value chain.

Lastly, some recommendations for future research could be outlined. This study only quantifies the direct economic return to government from PGI programs in Chile, measured by mining tax revenues. There are several indirect economic benefits, such as employment, intersectoral links and mining value added, which are not included here. Moreover, Häggquist and Söderholm (2015) remarks that PGI not only affects the exploration and mining industry, but has a key role in the sustainable development of a country. It has positive effects on other natural resources industries, on environmental planning and land management, and on a wide spectrum of other social and economic activities. Research on these topics could be complementary to the results of this study to give support to PGI programs in Chile.

Acknowledgements

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Appendix A. Schematic diagram of the evaluation model

See appendix Fig. A1.

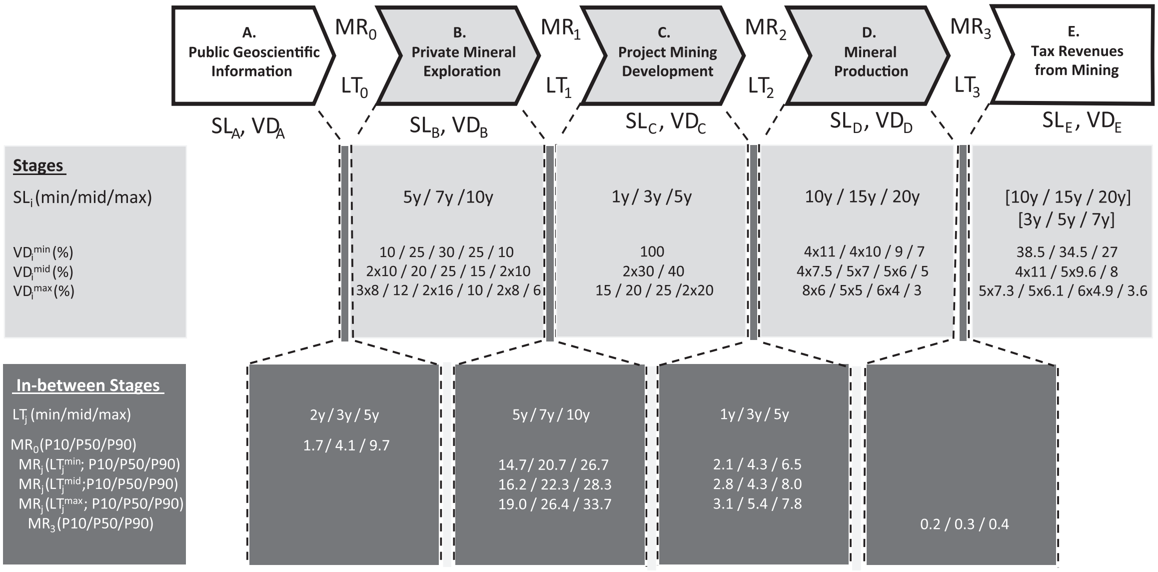

Fig. A1. Schematic diagram of the evaluation model used in this study to assess the direct economic return to government of PGI investment in Chile. SL_i, length of the ith stage in years (triangular distribution: minimum, mean and maximum). VD_i, value distribution factor of the ith stage in percentage per year (dependent of SL_i). LT_j, lag time between consecutive stages in years (triangular distribution: minimum, mean and maximum). MR_j, multiplier effect ratios between consecutive stages (lognormal or normal distribution: percentiles 10, 50 and 90); dependent of LT_j). See the text for more details.

Appendix B. MR_1, MR_2 and MR_3 moving average series charts and other values of moving average combination

See appendix Fig. B1 and Table B1

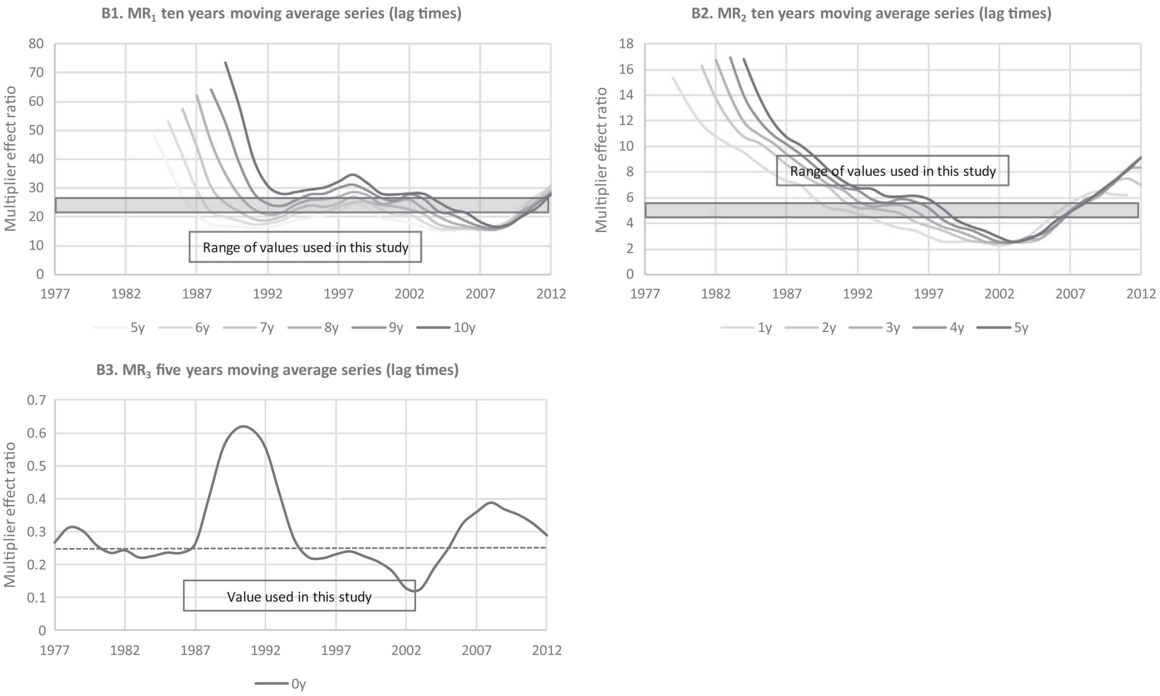

Fig. B1. Moving average series charts for MR_1, MR_2 and MR_3. 1) MR_1 ten years moving average for different lag times between exploration and mineral development; grey box represents the range of values used in this study; 2) MR_2 ten years moving average for different lag times between mineral development and mine production; grey box represents the range of values used in this study; 3) MR_3 five years moving average for no lag time between mine production and tax revenues; dotted line represents the value used in this study.

Table B1
Multiplier effect ratios and lag times between stages of the PGI value chain in Chile for other moving average combinations.

MR_j	LT_j	MM4	MM5	MM8	MM9	MM10
MR_0	-	Lognormal x = 5,12; σ = 3,86				
MR_1	5 A	Normal x = 26,21; σ = 16,18	Normal x = 24,76; σ = 14,45	Normal x = 21,54; σ = 7,53	Normal x = 20,99; σ = 5,84	Normal x = 20,71; σ = 4,68
	6 A	Normal x = 26,89; σ = 17,81	Normal x = 24,85; σ = 14,86	Lognormal x = 22,37; σ = 9,00	Lognormal x = 21,7; σ = 6,29	Normal x = 21,45; σ = 4,75
	7 A	Lognormal x = 29,73; σ = 36,57	Normal x = 24,62; σ = 13,24	Normal x = 22,62; σ = 6,60	Normal x = 22,42; σ = 5,61	Lognormal x = 22,27; σ = 4,72
	8 A	Normal x = 26,94; σ = 14,74	Normal x = 24,75; σ = 11,57	Normal x = 23,55; σ = 6,58	Normal x = 23,33; σ = 5,51	Normal x = 23,36; σ = 4,93
	9 A	Lognormal x = 30,58; σ = 14,89	Normal x = 25,5; σ = 10,9	Lognormal x = 24,79; σ = 7,24	Normal x = 24,60; σ = 5,70	Normal x = 24,75; σ = 5,33
	10 A	Normal x = 27,88; σ = 12,15	Normal x = 26,6; σ = 10,4	Normal x = 26,04; σ = 6,52	Lognormal x = 26,18; σ = 6,13	Normal x = 26,35; σ = 5,71

(continued on next page)

Table B1 (*continued*)

MR_j	LT_j	**MM4**	**MM5**	**MM8**	**MM9**	**MM10**
MR_0	-	Lognormal x = 5,12; σ = 3,86				
MR_2	1 A	Lognormal x = 4,98; σ = 2,88	Lognormal x = 4,92; σ = 2,99	Lognormal x = 4,94; σ = 4,55	Normal x = 4,39; σ = 1,89	Normal x = 4,28; σ = 1,74
	2 A	Lognormal x = 5,47; σ = 3,08	Lognormal x = 5,40; σ = 3,24	Lognormal x = 5,07; σ = 3,53	Normal x = 4,73; σ = 2,11	Normal x = 4,59; σ = 2,57
	3 A	Lognormal x = 5,96; σ = 3,28	Lognormal x = 5,85; σ = 3,39	Normal x = 5,20; σ = 2,46	Normal x = 5,04; σ = 2,24	Lognormal x = 4,98; σ = 2,57
	4 A	Normal x = 6,39; σ = 3,33	Lognormal x = 6,24; σ = 3,40	Normal x = 5,57; σ = 2,58	Normal x = 5,33; σ = 2,24	Lognormal x = 5,17; σ = 2,08
	5 A	Lognormal x = 6,76; σ = 3,51	Normal x = 6,54; σ = 3,25	Normal x = 5,88; σ = 2,52	Normal x = 5,61; σ = 2,12	Normal x =,43; σ = 1,84
MR3	-	Lognormal x = 0,26; σ = 0,09	Normal x = 0,26; σ = 0,08	-	-	-

Appendix C. NPV and IRR probability distribution functions for the risk-based central case

See appendix Fig. C1 and C2

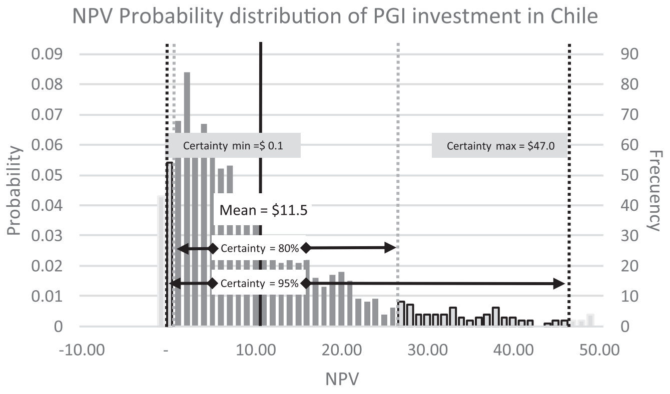

Fig. C1. NPV (benefit-cost ratio) probability distribution function for the risk-based case.

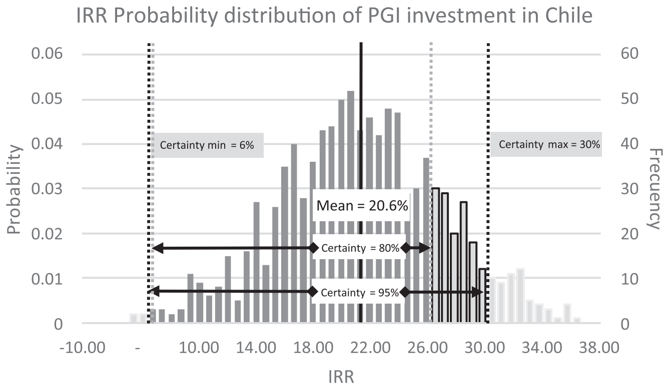

Fig. C2. IRR probability distribution function for the risk-based.

Appendix D. IRR results of individual variables effects

See appendix Fig. D1

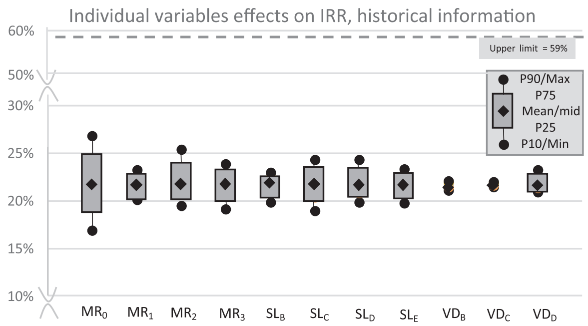

Fig. D1. IRR results of individual variables effects.

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