# Growth and green income: evidence from mining in Chile

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**Abstract**

This paper estimates the true economic income for the Chilean mining sector, using the welfare foundations for the usual net domestic product (NDP) income measure of the traditional National Accounts System (NAS) provided by [Weitzman, M., 1976. On the welfare significance of national product in a dynamic economy. Quarterly Journal of Economics. 90, 156–162; Weitzman, M., 2000. The linearised Hamiltonian as comprehensible NDP. Environment and Development Economics. 5, 55–68]. The total depletion of natural capital caused by mining is calculated by estimating, on the one hand, the depreciation of resources (using the net price approach) and, on the other, the environmental costs provoked by mining activity. The results show that, correcting the usual GDP measure for man-made capital depreciation plus the total loss of natural capital, the standard mining GDP measure of the NAS overestimates by 31–36% the economic income generated by Chile's mining sector during the period 1985–1996.

*Keywords:* Environmental accounts; Natural capital depreciation; Sustainability

## Introduction

In the last two decades of the 20th century, Chile showed better economic performance than the rest of the Latin American and Caribbean region. It exhibited an average annual growth rate of around 7%; higher than any country in the region and more than two times the rate at which the entire region grew on average (Perry and Leipziger, 1999).

Chile's economic growth has been based mainly on the exploitation and exportation of natural resources. Even though during the last decades the volume of manufacture exports increased, still close to 90% of country's total export value corresponds to unprocessed and processed natural resources (Figueroa et al., 1996). As a consequence, there has been a depletion of natural assets, which has reduced the country's wealth, and a large environmental degradation, which has negatively affected the population's welfare. Several works[1] have estimated the impact of such problems in different natural resource sectors, showing that the Gross Domestic Product (GDP) and the Net Domestic Product (NDP) measures of the traditional National Account System (NAS) do not take into consideration the depreciation of natural resources and the degradation of the environment in their cost sides. As a result, by disregarding the loss of natural wealth that occurs every year, the traditional measures of the NAS overestimate the national income of each year and its growth over time.

Among natural resources, mineral resources are particularly prone to depreciation since they are not renewable. This explains the increasing interest in estimating mineral resource depreciation in developing countries to obtain more accurate measures of the 'true' economic income produced by their mining sectors.

This paper presents and analyzes measures of the depreciation of natural resources and environmental

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[1] See Gomez-Lobo (1991) and Echeñique and Figueroa (1996) for the fishing sector, Núñez (1992) for the forestry sector, and Figueroa et al. (2002) for the copper sector.

services for the Chilean mining sector during the 1985–1996 period. These measures are used to correct the traditional income measures of the NAS, yielding corrected measures of NDP. The paper extends previous work in the area in two different ways. First, contrary to previous studies that worked only with copper[2], this paper presents the first comprehensive measure of resource depreciation in the entire mining sector of Chile since it includes estimations for oil and three main mineral resources (calcium carbonate, copper and gold). Second, for the first time it incorporates an estimation of environmental degradation in the mining sector to produce a more inclusive correction of the traditional NAS measures.

In the following section a short revision of the relationship between sustainability and economic growth is presented. Section 3 presents a simple model to correct the traditional NDP measure for the net loss of natural capital in the economy. Section 4 analyzes the data used to empirically apply the model of Section 3, and shows the results obtained. Finally, in the last section the main conclusions and lessons obtained are presented.

## A model of economic income

This section presents an optimal growth model, which follows Hamilton (1994, 2000). The model is based on Hartwick (1990) who demonstrates that Net Domestic Product (NDP) is equal to the current value Hamiltonian that solves the welfare maximization problem of utility subject to constraints in resource and capital endowments.

The model supposes a closed economy that produces a composite good, has a stock of a non-renewable natural resource and maximizes welfare within an infinite time horizon, according to:

$$\text{Max} \int_0^\infty U(C)\mathrm{e}^{-\rho t}\mathrm{d}t \tag{1}$$

subject to

$$\dot{K} = F(K,E) - C - f(E,Z) - g(D,M) - \delta K \tag{2}$$

$$\dot{Z} = -E + D \tag{3}$$

$$\dot{M} = D \tag{4}$$

where, $C$ is aggregate consumption, $K$ is the stock of man-made capital, $\dot{K}$ is net investment in man-made capital, $\delta$ is its rate of depreciation, $Z$ is the stock of the non-renewable natural resource (the stock of natural capital of the economy)[3], $E$ is the extraction rate of this non-renewable resource, and $D$ represents new discoveries of this resource. $M$ is the stock of discoveries. $F(K,E)$ is the production function of the composite good of the economy. The function $f(E,Z)$ is the total cost of extracting the non-renewable resource. Finally, $g(D,M)$ is the function representing the discovery costs for this non-renewable natural resource, with $g_D > 0$ and $g_M > 0$. Additionally, for any variable $J$, $\dot{J} = \partial J/\partial t$.

The current value Hamiltonian for the problem in Eqs. (4)–(9) is:

$$H = U(C) + \lambda_1(\dot{K}) + \lambda_2(M) + \lambda_3(\dot{Z}) \tag{5}$$

Obtaining the first order conditions and the optimal values for the shadow prices, the λs, and replacing these optimal values in the Hamiltonian, we obtain:

$$\begin{aligned} H = {} & U + U_c\dot{K} - U_c(F_E - f_E)(-E + D) \\ & + U_c(g_D - (F_R - f_E))D \end{aligned} \tag{6}$$

Assuming a linear utility (welfare) function $U = U_cC$, non-decreasing in $C$, as the one proposed by Hartwick (1990), and dividing Eq. (6) by $U_c$, a monetary expression of the value of the Hamiltonian is obtained, which provides an expression for NDP according to Weitzman (1976):

$$\text{NDP} = C + \dot{K} - (F_E - f_E)E + g_D D \tag{7}$$

The first two terms in the right hand side of (7) are the traditional measure of the NDP of a closed economy (consumption plus net investment in man-made capital). The last two terms correspond to the necessary corrections to calculate a green NDP measure that incorporates the depreciation of natural resources (the natural capital), which is not included in the usual measures of the national account system. The term $(F_E - f_E)$ corresponds to the marginal unit rent of the non-renewable resource in the model. Therefore, the third term of the expression subtracts the net depreciation of the non-renewable natural resource valued at its marginal rents. Moreover, $g_D$, is the marginal cost of new discoveries of the non-renewable resource, and the last term adds the value of new reserves of the non-renewable resource valued at the marginal discovery cost. Then, $g_D D$, can be seen as investment for new discoveries of the non-renewable resource, also known as exploration investment.

An important point to understand is that, in the traditional national account system, exploration costs are included within the investment accounts of the whole economy, and therefore they are already included in the NDP measure of the economy. This implies that to correct the NDP of the whole economy to obtain a green-NDP measure (i.e. corrected by natural capital depreciation) the last term in (7) should be disregarded. On the other hand, to obtain a corrected NDP measure for the non-renewable resource sector only that term should be added, since exploration costs are recorded by the national accounts

[2] See Figueroa et al. (2002).

[3] The total capital stock of the economy is therefore constituted by the stock of man-made capital, $K$, plus the stock of the natural resource ($Z$).

systems in the investment accounts of other sectors of the economy (Calfucura, 1998).

Following Hamilton (2000), it is possible to extend the model in Eqs. (1)–(4) to incorporate environmental services, $B$. The model assumes now that the welfare of the economy, which ought to be maximized, is now a function not only of consumption but also of the flow of environmental services and amenities, $B$, provided by nature. This flow is assumed to be negatively affected by the cumulative stock of pollution, $W$, so $B=\phi(W)$, and $\partial B/\partial W<0$. As previously, the composite good is still consumed and invested in artificial capital, but now it can also be invested at a rate '$a$' to reduce pollution. It is also assumed that polluting emissions, $e=e(F,a)$, are a function of the rate of production of the economy—$F(K,E)$—and the expenditure to abate pollution—$a$. Moreover, $\partial e/\partial F>0$ and $\partial e/\partial a<a$, and there is certain quantity of pollution, $h$, that is abated by nature itself. Therefore, the motion equation for the stock of pollution is $\dot{W}=e(F,a)-h(W)$.

Solving the welfare maximization problem with these new assumptions, and using again a linear welfare function to divide the Hamiltonian to evaluate at each moment of time, it is possible to derive a new expression for NDP:

$$\mathrm{NDP} = C + \dot{K} - (F_E - f_E)E + g_D D - \omega(e-h) \quad (8)$$

where the fifth term on the right-hand side of (8) subtracts the depreciation of environmental services, $(e-h)$, valued at the social marginal pollution abatement cost, $\omega$.[4] Then, Eq. (8) can be used to obtain a corrected measure of NDP, which now incorporates not only the depreciation of the non-renewable resource due to extraction but also the depreciation of environmental resources due to contamination.

To empirically apply this model it is necessary to overcome an empirical difficulty created by the term $(F_E-f_E)$ in (8). This expression corresponds to the price of the non-renewable resource in situ, which is also called the marginal unit rent of the resource. On the other hand, $P$ is the market price of the extracted resource and, in equilibrium, is equal to $F_E$, so the marginal unit rent of the resource can be also expressed as $(P-f_E)$. However, in the real world it is very difficult in general to obtain information about the term $f_E$—the marginal cost of exploiting the resource—in this expression. The case of mining resources in Chile is not an exception. Thus, instead of estimating the marginal unit rent of the resource in this work we follow the usual practice of using the average cost, $\mathrm{AC}(E)$, instead of the marginal cost, to calculate the net price or rent. This implies that if the marginal cost of exploitation is increasing, then marginal cost will be greater than average cost and the expression $[P-\mathrm{AC}(E)]E$ overestimates the depreciation value in Eq. (8) (Hartwick, 1990)[5]. To solve this problem we follow here Figueroa et al. (2002) in using the methodology proposed by Davis and Moore (2000). Employing more general assumptions than the restrictive assumptions of homogenous mineral reserves and constant return to scale in resource extraction, Davis and Moore derived an 'unrestricted valuation principle' (UVP) for valuing mineral resources in the ground (in situ) and calculated correcting factors to use average instead of marginal costs when estimating Hotelling rents for different resources in the USA. They showed that in the absence of more specific data these correcting factors should be used for empirically correcting resource valuations for oil and minerals in other countries.

Figueroa et al. (2002) argue that the approach proposed by Davis and Moore (2000) should be used also because there is no similar empirical result estimated yet for the specific case of other resources in other countries due basically to lack of reliable data. Therefore, it is more accurate to employ Davis and Moore's correcting factors than simply assuming a straight average cost-based valuation principle (which is conceptually equivalent to assume a correcting factor of 1). Moreover, these authors are confident in proposing a correcting factor of 0.7 for hard-rock minerals in general and 0.6 for oil. Finally, the 'true' correcting factors depend on the extracting technology employed in the mining processes, and the mining sector in Chile, both private and public, has been characterized by a highly efficient technology and cost structure, very similar to most mining industries in the US and other developed countries (Figueroa et al., 1999).

Therefore, the suggestion of Davis and Moore is adopted here but new discoveries are valued at average costs, and Eq. (8) is changed in the following way to obtain the green NDP measures of Chile's mining sector:

$$\mathrm{NDP} = \text{Economic Income} = C + \dot{K} - \alpha\,\{[P-\mathrm{AC}(E)]E\} - w(e-h) + g_D D \quad (9)$$

where the correction factor $\alpha$ corresponds to the slope parameter of Davis and Moore's unrestricted valuation principle; and, $P$ is the market price of the exhaustible resource (which in equilibrium is equal to $F_E$), and $\mathrm{AC}(E)$ is the average cost of exploiting the exhaustible resource. Therefore, to calculate the green-NDP measures reported in this article Eq. (9) is employed.

[4] $\omega$ is valued at the optimal point.

[5] Nordhaus and Kokkelenberg (1999) present five alternative methods to estimate natural resource depreciation: Net price I and II, net present value, replacement cost and transaction price. They discuss the advantages and disadvantages of each one of these methods, noting that the net price approach is prone to 'systematic overvaluation of reserves' (p. 72). The model used here estimates the value of the addition of reserves through the marginal cost of new discoveries instead of the net price method and therefore does not incur in this type of overestimation. A possible disadvantage of the approach used here is its assumption of economic equilibrium in exploration activities.

## Estimation of economic income for the mining sector in Chile

This section shows how we estimate the monetary value of the depreciation of non-renewable resources resulting from extracting activities and the monetary value of the depreciation of environmental services provoked by pollution from the mining sector in Chile during the period 1985–1996. It also presents the calculated NDP corrected measures obtained by correcting the usual NDP measures of the traditional national account system according to Eq. (9) above.

### *Methodological aspects*

The scarcity of information on natural resources and pollution in Chile restricted our calculations of corrected NDP to the 1985–1996 period. The empirical work considers mineral (non-renewable) resources—calcium carbonate, copper, gold and oil—and air pollution by sulfur dioxide ($SO_2$) in the main State-owned smelters of copper in Chile.

*Traditional macroeconomic figures*

The traditional macroeconomic figures used in this study are those of the official statistics of the Central Bank of Chile, specifically from the National Account Annals for the period 1985–1996 (Central Bank of Chile, 1999). The estimation of the depreciation of physical capital in current pesos was obtained from Figueroa et al. (2002) and corrected using the implicit deflator for Chile's mining GDP. These estimates, as well as all the other figures calculated in Chilean currency, were transformed to US$ of year 2000, using the consumer price index and the so-called 'observed' exchange rate of the Chilean money exchange market, both obtained from the Central Bank statistical series.

*Natural resource depreciation*

The estimations of the values of Chile's mining resource depreciation use a constant net price calculated for the base year 1986, according with the norm of the National Account System (NAS). This is in spite of the fact that resource depletion should be valued using the long run equilibrium net price resulting from an intertemporal maximization process. However, the approach followed by Gómez-Lobo (1991) and Núñez (1992) is employed here, valuing with a unit rent of a base year. According to Gómez-Lobo (1991), the best alternative is to use the net price implicit in the resource valuation made by the NAS employing the value of the production of a given base year that is kept constant. Even though this net price may still not reflect the long run equilibrium condition, any divergence between the calculated value and the value of the product will be systematic and will not affect the trend. In the same way, when Repetto et al. (1989) calculate the value of natural resource depreciation they do not include the capital gains or losses resulting from price variations, and they include them in an special account.

The unit rent (net price) for each natural resource included here was calculated from the data of the 1986 Input–Output Matrix (Central Bank of Chile, 1991), according to the following procedure: (1) starting with the gross value of production, value added is obtained by subtracting intermediate consumption; (2) from value added the total rent of the resource is calculated by subtracting salaries, fixed capital consumption and alternative cost of capital; and (3) by dividing the total rent of the resource by total resource extraction the unit rent is calculated.

The mineral resource unit rents were obtained from Calfucura (1998), where the alternative cost of capital corresponds to the average annual adjustable interest rate for borrowing in the Chilean banking system in the 1985–1994 period, which was approximately 9%.

To calculate the mining capital stock, a capital/GDP rate was estimated for the mining sector using net fixed asset data from the annual balances of Copper Corporation (CODELCO)[6] and other firms of copper mining sector. The calculated capital/GDP rate is 2.9, which is consistent with the higher capital intensity of the mining sector vis à vis the rest of the Chilean economy. The extracted quantity of mineral resources of each year was obtained from the Geology and Mines National Service (SERNAGEOMIN)[7].

*Environmental services depreciation (environmental degradation)*

The depreciation of environmental services incorporated here is the value of the environmental degradation provoked by mining atmospheric pollution. Due to the lack of empirical data, this value includes only the abatement costs of sulfur dioxide for the main smelters of cooper in Chile.

The $SO_2$ series for 1989–1996 was obtained using the available information on $SO_2$ emissions from the three major smelters owned by the State during this period: Chuquicamata, Hernán Videla (Paipote) and Ventanas, as reported by IAP (2002). Since there are no measures of $SO_2$ for years previous to 1989, the $SO_2$ emissions for 1985–1988 were estimated from the evolution of an index of refined cooper production by CODELCO and the National Mining Enterprise (ENAMI)[8].

The monetary costs of pollution abatement were estimated using data from Lagos et al. (2002). The abatement costs of $SO_2$ emissions for the three State-owned refineries already mentioned were calculated.

[6] It corresponds to Corporación Nacional del Cobre (CODELCO) the public Chilean mining enterprise.

[7] It corresponds to Servicio Nacional de Geología y Minas (SERNAGEOMIN).

[8] It corresponds to Empresa Nacional de Minería (ENAMI), a State-owned company that works with smalls mining producers in Chile.

Table 1
Chile: value of natural resource depreciation and environmental degradation in mining; 1985–1996 (Millions of US$ of 2000)

| Year | Cooper | Oil | Gold | Calcium carbonate | Total resource depletion | Environ-mental degradation costs | Total natu-ral capital loss | Exploration costs (*) | Net loss of natural capital |
|---|---|---|---|---|---|---|---|---|---|
| 1985 | 223 | 70 | 58 | 5 | 356 | 93 | 449 | 71 | 378 |
| 1986 | 230 | 66 | 60 | 5 | 362 | 101 | 462 | 60 | 402 |
| 1987 | 233 | 59 | 57 | 6 | 355 | 86 | 441 | 57 | 384 |
| 1988 | 238 | 48 | 69 | 7 | 363 | 88 | 451 | 49 | 402 |
| 1989 | 264 | 44 | 76 | 7 | 391 | 80 | 471 | 75 | 396 |
| 1990 | 261 | 39 | 92 | 7 | 399 | 84 | 483 | 83 | 400 |
| 1991 | 298 | 35 | 97 | 8 | 438 | 66 | 504 | 110 | 394 |
| 1992 | 318 | 29 | 116 | 9 | 472 | 57 | 529 | 154 | 375 |
| 1993 | 338 | 28 | 113 | 11 | 490 | 51 | 541 | 170 | 371 |
| 1994 | 365 | 24 | 130 | 12 | 531 | 35 | 566 | 164 | 402 |
| 1995 | 409 | 21 | 150 | 11 | 591 | 31 | 622 | 132 | 490 |
| 1996 | 512 | 18 | 178 | 12 | 720 | 32 | 753 | 210 | 543 |
| AVERG 1985–1996 | 307 | 40 | 100 | 8 | 456 | 67 | 523 | 111 | 412 |
| % of total natural capital loss | 59 | 8 | 19 | 2 | 87 | 13 | 100 | 21 | 79 |

(*) Exploration costs corresponds to a negative natural resource depreciation, i.e. an addition to the stock of minerals. Total natural capital loss = total resource depletion + environmental degradation costs. Net natural capital loss = total resource depletion + environmental degradation costs − exploration costs.

The marginal abatement costs for $SO_2$, estimated at the level of the existing environmental norm for this pollutant, were US$186 in Ventanas and US$181 in Paipote.[9] For the Chuqicamata smelter, the estimated marginal cost was US$107, but in this case the environmental norm is not complied. The reason of this is that, even though this smelting facility complies with the emission reduction of its decontamination plan, its target emission level is overestimated and, therefore, its $SO_2$ concentrations never reach levels below saturation. Nevertheless, we use this estimated value because the lack of an adequate target level does not allow this smelter to comply with the norm and, therefore, it is not possible to calculate the marginal cost at the level of compliance. The implication of this is that the costs of air contamination provoked by the mining smelting facilities are underestimated.

*Exploration costs*

In order to correct the mining-sector accounts it is necessary to add exploration costs as indicated by the fifth term on the right hand side of Eq. (9). It is worth mentioning that this procedure is in line with the prescriptions of studies of the Bureau of Economic Analysis in the US dealing with income accounting for several non-renewable resources (BEA, 1994a,b).

When applying this methodology we are implicitly using average exploration costs and therefore, if marginal exploration costs exceed average exploration costs as it is usually assumed, the fifth term in Eq. (9) would be underestimated. Unfortunately, the lack of data in Chile precludes us to calculate marginal exploration costs. However, as it is demonstrated below, exploration costs have a relatively insignificant effect when correcting for green NDP and, therefore, the possible bias would be even more insignificant in terms of that correction. In this study, a series of exploration costs for the entire mining sector of Chile was obtained from Mackenzie et al. (1995) for the period 1977–1991, and from Concha (1997) for the period 1992–1996. The exploration costs were corrected using the implicit deflator for Chile's mining GDP.

*Results*

*Value of non-renewable natural resource depreciation*

The estimated values of the depreciation of non-renewable natural resources (copper, oil, gold and calcium carbonate) for the period 1985–1996 in Chile are presented in columns 2–5 of Table 1.

Table 1 shows that the largest depreciation of mineral resources corresponds to the copper mining sub-sector, which is explained by the large participation of this metal in Chile's total mining production. In fact, the annual average depreciation in the copper sub-sector is 7.7 times the one of the oil sub-sector, 3.1 times the one of gold sub-sector and 38 times the one of the calcium carbonate sub-sector. The second largest loss of natural capital is associated with gold. In the case of oil, the loss of natural capital is decreasing through the period, due to the increasingly smaller extraction levels of this mineral during the more recent years, which are explained by reserve depletion in the southern extreme of the country. The calcium carbonate sub-sector presents the lowest depreciation value, according with its small relative participation within the total national mining product.

[9] In US$ of 1998.

Table 2
Chile: average annual depreciation of natural capital by extractive mining activity; 1985–1996 (% of each sub-sector's GDP)

| Sub-sector | Depreciation |
|---|---|
| Copper | 13 |
| Oil | 10 |
| Gold | 24 |

Table 2 provides a picture of the relative importance of the value of resource depreciation in the four mining sub-sectors studied here. It presents the average value of the annual depreciation for each of these non-renewable resources during the entire 1985–1996 period under analysis, shown as a percentage of the GDP of each sub-sector. The figures imply that, on average, gold is the extractive activity that has generated the largest relative loss of natural capital (24% of gold GDP), followed by copper (13% of copper GDP) and oil (10% of oil GDP), which is explained by the larger rents generated in gold mining. Unfortunately, there is no data in Chile to calculate the calcium carbonate-GDP figure accurately.

*Environmental services depreciation*

Regarding air pollution generated by the mining activity, column 2 of Table 1 shows that its annual value increased the first 2 years, to fall then from 1987 on. This way, the value of environmental degradation reached US$93 million in 1985, grew to $101 million in 1986, and declined to $32 million in 1996. The reduction in the value of environmental degradation is explained by the successful air decontamination policies implemented in the state-owned smelters during the decade of the 1990s (Lagos et al., 2002).

Table 1 as well as Fig. 1 show the relative significance of environmental degradation vis *á* vis the depreciation of natural resources, illustrating the fact that, on average, the former represents every year a 13% of calculated total natural capital loss (column 8 of Table 1).

It is worth presenting in a broader context the figures of natural resources and environmental services depreciations calculated here. Column 10 of Table 1 shows the annual Net Loss of Natural Capital, which results from subtracting from total capital loss (the depreciation of the stocks of natural resources plus the depreciation of environmental services, shown in column 8 of Table 1) the exploration costs (shown in column 9 of Table 1), since every year exploration costs (discoveries) represented additions to the stocks of natural resources (appreciations of these stocks). As it is also shown in Fig. 1, the Net Loss of Natural Capital was quite stable during the first 10 years of the period, averaging US$390 millions per year, but it increased sharply, to an average of US$517 millions per year, for the last 2 years of the period—1995 and 1996, which represents an increase of 33%.

Fig. 2 shows the Net Loss of Natural Capital expressed in terms of total-GDP and mining-GDP. It can be seen that for the 1985–1996 period, the net loss of natural capital was between almost 0.7% and more than 1.2% of total-GDP and between almost 9% and almost 13% of mining-GDP, which represent considerable magnitudes. Moreover, there are other non-renewable resources (iron, silver, etc.) and environmental services (soil, water, etc.) that, due to the lack of data, we have not included in our estimates of the value of total (resource plus environmental) natural capital loss (depreciation) calculated here. Thus, it should be expected that incorporating the depreciation suffered by these other natural resources and environmental services would increase those percentages.

*Corrected NDP measures*

The estimated figures of monetary values of the depreciation of non-renewable natural resources and the degradation of environmental services in the mining sector presented in the previous section were used to correct the net domestic product (NDP) figures presented in the traditional national account system. This way, three different measures

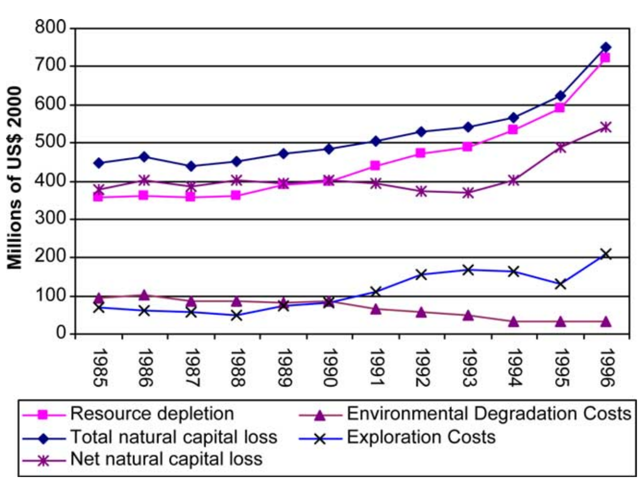


Fig. 1. Chile: value of natural resource depreciation and environmental degradation in mining; 1985–1996.

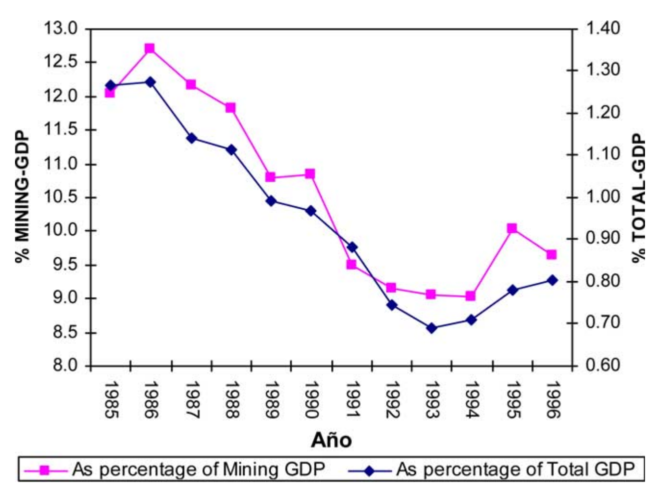


Fig. 2. Chile: net natural capital loss in mining as a percentage of mining and total GDP; 1985–1996.

Table 3
Chile: corrected mining-NDP; 1985–1996 (million of US$ of 2000)

| Year | Traditional measures (NAS) | | Corrected measures (calculated here) | | |
|---|---|---|---|---|---|
| | GDP | NDP | NDP-C1 | NDP-C2 | NDP-3 |
| 1985 | 3135 | 2662 | 2306 | 2213 | 2284 |
| 1986 | 3163 | 2578 | 2216 | 2116 | 2176 |
| 1987 | 3153 | 2736 | 2382 | 2296 | 2353 |
| 1988 | 3400 | 3087 | 2724 | 2636 | 2685 |
| 1989 | 3665 | 3337 | 2946 | 2866 | 2941 |
| 1990 | 3699 | 3340 | 2941 | 2856 | 2939 |
| 1991 | 4157 | 3646 | 3208 | 3142 | 3252 |
| 1992 | 4097 | 3527 | 3055 | 2999 | 3153 |
| 1993 | 4090 | 3313 | 2824 | 2772 | 2943 |
| 1994 | 4454 | 3832 | 3300 | 3266 | 3430 |
| 1995 | 4870 | 4359 | 3768 | 3737 | 3870 |
| 1996 | 5637 | 4820 | 4100 | 4067 | 4277 |
| GDP/NDP | | 1.15 | | | |
| GDP/NDP-C1 | | | 1.33 | | |
| GDP/NDP-C2 | | | | 1.36 | |
| GDP/NDP-C3 | | | | | 1.31 |
| NDP/NDP-C1 | | | 1.15 | | |
| NDP/NDP-C2 | | | | 1.18 | |
| NDP/NDP-C3 | | | | | 1.14 |
| Average growth rate 1985–1996 | 5.48 | 5.54 | 5.37 | 5.69 | 5.87 |

Notes: GDP = mining sector GDP of the traditional national account system; NDP = mining sector NDP of the traditional national account system = GDP − man-made capital depreciation; NDP-C1 = NDP − natural resource depreciation (calcium carbonate, copper, gold and oil); NDP-C2 = NDP − natural resource depreciation − environmental service degradation (mining air pollution) = NDP-C1 − environmental service degradation; NDP-C3 = NDP − natural resource depreciation − environmental service degradation + exploration costs = NDP-C2 + exploration costs.

of corrected-NDP for Chile are calculated, which are called NDP-C1 to NDP-C3 and are reported in Table 3.

Columns 2 and 3 of Table 3 show the usual measures of Chile's mining gross domestic product (GDP) and mining net domestic product (NDP) as reported by the traditional NAS.[10] In the lower panel of the table it is possible to observe (first row in the third column) that for the period under analysis, 1985–1996, the GDP measure was on average 15% higher than the NDP measure each year.

Columns 4–6 present the three corrected-NDP measures calculated here, NDP-C1, NDP-C2 and NDP-C3. To produce the first of these corrected measures, we subtract from the traditional NDP measure the depreciation of non-renewable resources (calcium carbonate, copper, gold and oil) that occurred each year (the figures in Table 1).[11]

It is important to note in the lower part of Table 3, that the mining-GDP figure of the traditional NAS overestimates by 33% this first corrected-measure (NDP-C1) of mining-NDP.[12] This implies that when the traditional GDP measure is used to indicate the economic income generated by the mining sector of the economy in a given year and its associated welfare level, this traditional measure overestimates by approximately one third the true economic income according to this corrected measure calculated here (NDP-C1). Moreover, it is possible to see that the traditional NDP measure reported by the NAS overestimates by approximately 15% the NDP-C1 measure produced here. Note that a half of the overestimation of GDP over NDP-C1 represents failure to account for depreciation of man-made capital and the other half represents failure to account for depreciation and degradation of natural capital.

The second corrected-NDP measure calculated in this paper, NDP-C2, is shown in column 5 of Table 3, and it corrects the traditional mining-NDP measure of the NAS by subtracting from it not only the depreciation of natural resources, as in the case of NDP-C1, but subtracting also the environmental costs caused by the air pollution generated by the mining sector.[13] The lower panel of the table shows that the GDP measure reported by the NAS overestimates by 35% this corrected measure of NDP, and the NDP measure reported by the NAS overestimates it by 17%.

Finally, the third corrected-NNP measure calculated, NDP-C3, is shown in column 6 of Table 3. This NDP-C3 measure corrects the NDP of the traditional NAS by subtracting both the depreciation of natural resources and the depreciation of environmental services and by adding the mining exploration costs. The lower part of the table shows that mining-GDP reported by the NAS overestimates by 30% this corrected measure of mining-NDP (NDP-C3), and that the NAS measure of mining-NDP overestimates it by 14%.

These estimates indicate that the overestimation of the true economic income implied by the traditional measures of the NAS is significant and cannot be disregarded to appropriately assess the sustainability of the growth of the mining sector and the economy.

The last line at the bottom of Table 3 shows the growth rate of the different income measures for the entire period under consideration. It is evident that the corrected measures of the national income calculated in this paper show a larger growth rate than the growth rate of the traditional NAS measures. This is obviously due, on the one hand, to the evolution showed by the values of the environmental depreciation along the period, which

[10] To go from GDP to NDP, the depreciation of man-made capital is subtracted from the first.

[11] Note that in terms of Eq. (9), this NDP-C1 measures corrects the usual NAS measure of NDP (which corresponds to the first two terms of the right hand side of the equation) by subtracting from it the third term on the right hand side of the equation (but applied to not just one non-renewable resource like in the equation, but to the four considered here, i.e. calcium carbonate, copper, gold and oil).

[12] This figure of an overestimation of 33% is worth to be mentioned because the media and the public generally use GDP figures as indicators of economic activity and/or general welfare; NDP figures are used in general more technically.

[13] In terms of Eq. (9), this NDP-C2 measure corrects the traditional NDP expression, $(C+\dot{K})$, by subtracting the third and fourth terms in the right hand side of the equation, i.e. $-\alpha\{[P-\mathrm{AC}(E)]E\}$ and $-w(e-h)$.

implies that the correction made to the traditional income measures are larger at the beginning of the period, and, on the other hand, to the increasing additions of natural capital through exploration which were higher at the end of the period.

*Corrected mining-NDP within the Chile's economy context*

It seems useful to assess the significance of neglecting the depreciation of natural resource stocks from the point of view of the Chilean society and its economy as a whole. Chile's annual total natural capital loss caused by its mining sector amounted on average to almost 1% of country's total GDP for the entire period of 1985–1996 (Fig. 2).

Moreover, the magnitude of total net natural capital loss[14] generated by the mining activity appears quite significant compared to different forms of capital accumulation in Chile during the analyzed period. For example, throughout the period, mining's net natural capital loss is approximately two-and-a-half times the country's annual investment in R&D. Additionally, mining's net natural capital loss corresponds to about 35% of public investment in education during the period 1985–1996. On the other hand, given that national fixed investment amounted to an average of about 20% of GDP in this period, net mining natural capital loss corresponded on average to approximately 5% of fixed capital investment in Chile. Furthermore, it is important to keep in mind that the traditional income measures of Chile's mining sector have been corrected here only for some resource depreciation, which obviously underestimates the depreciation of all metallic and non-metallic mining resources of the country. This implies that, the significance of the total loss of natural capital generated by the mining sector is, compared to Chile's GDP, public investment in education or in R&D, much larger than the one already portrayed here considering only copper, oil, gold and calcium carbonate resource depreciation and depreciation of environmental services due to air pollution provoked by copper smelters.

## Discussion and conclusions

This work is a first effort to calculate a true measure of Chile's mining economic income (NDP) in a broad and comprehensive manner, taking into consideration the depreciation of natural resources as well as environmental degradation. The 'corrected' or 'green' NDP measure calculated here is an appropriate index of the true welfare of an economy at each moment in time (Weitzman, 1976, 2000).

*Need to estimate the loss of natural capital*

The estimates of the loss of natural capital (depreciation of natural resources and degradation of environmental services) and of corrected-NDP that have been presented in this paper show that between 14 and 18% of the mining-NDP measure of the traditional national account system corresponds to environmental costs of economic growth. These costs reduce the welfare of present and future generations. This is a percentage that cannot be disregarded and that corresponds to an average for the aggregate economy. Therefore, at the regional and sectoral level—especially in cities that have serious environmental problems—and in the mining sector, we should expect that the figures of the traditional NAS overestimate the welfare of each period in a much larger proportion.

During the last decades, there has been concern and controversy in Chile about the distributive effects of economic growth, due not only to the persistence of high levels of poverty in the country (over 20%), but also, and mainly, because Chile has a large income inequality according to international standards. There are some people who believe that the income distribution has worsened in the last decades, in spite of the exceptional growth shown by the Chilean economy.[15] Additionally, there is evidence that health effects caused by environmental pollution are suffered the most by the people in the poorest quintiles of the income distribution. Therefore, one can suspect that the relative welfare level of the poorest people has deteriorated during the last decades in Chile more than what the statistics of the NAS indicate.

*The importance of investing the rents*

The magnitude of mining depreciation in Chile makes it necessary that public policies invest the mining sector's rents in other forms of capital, mainly those associated to human capital, R&D, renewable natural resources, and man-made capital in productive activities in non-mining sectors of the economy. It is not impossible in the future that certain economic activities could become economically unfeasible due to depletion of resources, technological innovation or market conditions. If this occurs in certain mining activities, consumption possibilities of current and future generations would be affected. Therefore, the economic rents that currently are being generated in the mining sector of the country should be invested to develop other productive activities that could provide alternative ways to create jobs and economic growth.

The allocation of property rights over mineral resources and the tax structure levying their exploitation determine

[14] Which corresponds to the depreciation of natural capital (resources and environmental services) (column 8 in Table 1)minus the appreciation of the stock of natural capital through exploration (column 9 of Table 1).

[15] However, there is also evidence in the other direction. For example, Valdés (1999) calculates that, for the period 1987–1994, there was a small improvement in the income distribution in Chile, demonstrated by a small reduction in the Gini coefficient from 0.55 to 0.53.

the appropriation and disposition of the rents generated by these resources. In Chile, for many years, there have been voices denouncing that a large proportion of the rents of the mining sector are captured by foreign companies that send them out of the country. In this context, it is important to notice that often governments assign to private agents the rights to exploit mining resources when their countries do not have the money to finance the large investments needed to exploit these resources. During the 1980 and 1990s, many countries changed their policies to allow private investors to capture part of the mining rents in order to attract them to initiate or expand mining exploitations in their territories. The successful mining policy of Chile of the 1980s is an example. There are presumptions that the competition to attract foreign direct investment to their mining sectors has lead countries to a 'race to the bottom' when determining the rent extraction rates to levy on their mining resources licensed to private investors (Figueroa, 1999).

Finally, it is worth noticing that in contrast to other sectors, mining is an activity that generates and attracts very specific human capital and, therefore, the technological spillover to other sectors of the economy is low. Thus, to contribute to the long-run growth of the Chilean economy the mining sector's rents should be invested in human capital associated to other sectors with larger externalities or spillover capacity. In this way the mining activity of the country could contribute to reach a path of truly sustainable growth in the future.

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