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A CGE framework to evaluate policy options for reducing air pollution emissions in Chile

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ABSTRACT. Successful economic growth in Chile based on open market and export strategy, is characterized by a high dependence on natural resources, and by polluting production and consumption patterns. There is an increasing concern about the need to make potentially significant trade-offs between economic growth and environmental improvements. Additionally, policy makers have been reluctant to impose standards that could have regressive consequences, making the poor poorer. Using the CGE model ECOGEM-Chile we study the direct and indirect effects of imposing environmental taxes in Chile for PM-10 as well as taxes on fuels. We analyze the effects over macroeconomic variables as well as sectoral, distributive, and environmental variables. The results show that the most significant impacts are on emissions and sectoral outputs. There are winners and losers. Macroeconomic and distributional impacts are low when low emission reductions are required, however they can be significant if a 50% reduction in emissions are imposed.

1. Introduction

The debate on the need to balance economic growth and environmental impact appeared on the scene in 1972 when the Club of Rome issued its 'Limits to Growth' publication. Although this study had fundamental shortcomings because it did not take economic forces into account, it did generate much awareness on ecological matters. Ever since, the debate has continued with more and less controversial stands, but integrating environmental and economic variables more appropriately (*The Economist*, 1997; Dasgupta and Mäler, 1998; Kneese, 1998). In 1987, the Brundtland Commission defined the term 'sustainable development' as 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. In practice, this definition considers that any developing society must achieve its economic, environmental, and social goals simultaneously (Pearce and Turner, 1990). But how can policy-makers evaluate the impact of a given policy on each of

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these dimensions? How significant are the economic and social impacts of environmental policies in a developing context? How much better are optimal policies (such as emission taxes) than suboptimal policies (such as a fuel tax), and in what dimensions are they better?[1] This paper proposes the use of a general equilibrium framework to answer these questions and develops a model for Chile to assess quantitatively the significance of the impacts. A systematic approach to explore the impacts in all dimensions is presented.

The Chilean Environmental Framework Law, passed in 1994, incorporates the concept of Sustainable Development. It includes the idea that there can be no strong and stable progress unless social justice and environmental care exist at the same time, which increase the possibilities of fostering economic growth while protecting the environment, eliminating poverty and attaining more social equity. However there has not been any direct correspondence between these principles and practice in Chile. Policy evaluations and policy decisions relating to the environment are undertaken separately from those relating to economic and social objectives. In this context, this paper is the first to evaluate these three dimensions together for Chile.

Chile's growth rate in the past decade was one of the world's highest (7 per cent GDP average annual growth), and it coped fairly well, compared to all other Latin American countries, with the 1997–1998 Asian crisis. In this period, social policies have been significant, and have resulted in a remarkable improvement in health care and education. Also noteworthy is the 38 per cent and 60 per cent reduction in the number of extremely poor and poor, respectively, in less than ten years.

However, 23.2 per cent of the population is still below the poverty line, and the unequal distribution of income has not improved in the last 20 years (MIDEPLAN, 1999). Additionally, these bright economic and social achievements have left their mark on the country's natural and environmental capital. Economic growth has been largely based on primary product exports, directly related to the exploitation of natural resources. The ten leading products accounting for 65 per cent of exports were related to natural resources (refined copper, 25.8 per cent; copper ore, 12.1 per cent; wood pulp, 6.8 per cent; fresh fish, 4.5 per cent; meat and fish meal fodder 4.0 per cent; etc.). The impact on natural capital has not been recorded.

Economic growth has resulted in increasing pollution levels that affect the country's environmental quality. The development of manufacturing and mining industries, usually with little concern for the environment, together with the concentration of the population in cities, and the increasing number of privately owned vehicles, among other factors, have taken their toll on the quality of water, air, and soil, and thus on the people's quality of life.[2]

[1] Optimal in a cost-effective framework.

[2] The Index of Sustained Economic Welfare, albeit criticizable (Neumayer, 1999), was run for Chile (Castañeda, 1997), and showed that over the past 30 years, despite the accumulated growth of 88 per cent in production, welfare has decreased by an estimated 4.9 per cent, which shows the trend divergence since the financial crisis of 1982.

Environmental concerns voiced strongly by foreign governments, the population, and even firms,[3] at the end of the eighties, resulted in the creation of the National Environmental Commission (CONAMA) in 1990. With it the Chilean Administration took a step forward in unifying the environmental policies, through an agency that would identify the most critical aspects, create policies and monitor the enforcement of regulations, standards, and other applicable measures.

Sectoral policy makers, the private sector, and political and finance authorities fear that there is a significant tradeoff between a better environment and growth, the latter being required to solve the important social problems that still affect Chile. Since many of the most important economic sectors are related to natural resources, any action that reduces activity in these sectors may have negative regional and/or countrywide impacts. Investments in pollution reduction, in particular in Santiago, will require significant layouts, not necessarily paid exclusively by those affected.

Unfortunately policymakers in Chile – as in all developing countries – do not have the tools required to evaluate the impact on sustainability of potential policy instruments. This makes it difficult to choose the most preferable instrument and the level of reduction to be required. Generally, studies are made within a partial equilibrium framework, which makes it difficult to analyze the implications of environmental protection measures on equity and efficiency.

The complexity of direct and indirect relationships between economic, environmental, and social variables calls for models that allow evaluating priorities and policies consistent with sustainability. Computable General Equilibrium (CGE) models are multi-sector models which represent a country's economy in a more realistic way, and have proven to be useful instruments to describe these relationships, providing an *ex-ante* quantitative assessment of the multidimensional effects of different policies.

Initially, these models were applied to examine poverty and income distribution problems, although later trade issues took precedence among the applications. Today, environmental issues and social equity-related problems have moved up the priority scale, following the international diffusion of the concept of sustainable development.[4] The application of CGE models is important in a number of environmental aspects, including: trade policies or international trade agreements on the environment, climate change or global warming, energy problems, natural resource allocation or management, and economic impact of specific environmental regulations. These models are being used extensively today to evaluate the impact of greenhouse gas reduction policies.[5]

[3] See O'Ryan and Escudero, 1997.

[4] Keyzer, 1993, performs a review of computable general equilibrium model applications to developing countries.

[5] For models used to evaluate the effects of trade policies or international trade agreements on the environment see Lucas, Wheeler, and Hettige, 1992; Grossman and Krueger, 1993; Beghin *et al.*, 1996; Madrid-Aris, 1998, or diverse applications in the area of the Global Trade Analysis Program, GTAP. Models used to evaluate Climatic Change or Global Warming include Bergman, 1991; Jorgenson and

In this article, the CGE Model ECOGEM-Chile will be applied to analyze the direct and indirect effects of imposing new taxes on fuel and on PM-10 emissions, aimed at reducing PM-10 emissions by 10 per cent and 50 per cent. Using the model, the impact on PM-10 emissions, as well as SO_2, NO_2, CO, and VOC emissions are quantified, as well as the impact on production by sectors, macroeconomic variables, and income distribution. Questions addressed include: Will production, consumption, investment and trade be affected significantly? In what sectors? Will the poor or the rich bear the burden of the policies? Can this burden be made lighter for any of the affected parties by some offsetting policy? The results give important insights into the systemic impacts of environmental policies as well identifying and quantifying the potential impacts to the winners and losers.

Section 2 presents Chile's current air quality situation. Section 3 describes the taxes applied in the country. Section 4 describes the CGE model and the data used. Section 5 evaluates different environmental tax scenarios and alternative governmental compensation schemes to maintain the initial real public savings (expenditure) situation. The objective is to analyze tax reforms, which contribute to reduce the emission of different pollutants, without having negative impacts on economic and social variables. Section 6 presents the main conclusions.

2. Air quality in Chile

Social concerns regarding the environment experienced a visible increased in Chile in the last decade. The estimated public expenditure on environmental issues reached US$297 million in 1999, including US$156 million in capital expenditures.[6] In 2000, the public environmental budget rose to US$307.5 million, with a bit more than half in capital expenditures (CONAMA, 2001). According to these recent figures, public environmental expenditures in Chile stabilized at around 1.85 per cent of the total public budget (0.48 per cent of GDP). The environment-related expenditures by CONAMA, Ministries of Economy, and Mining and Forestry National Corporation are 50 times more than in 1990. Private expenditures also grew noticeably. For example expenditures linked to environmental impact assessments increased ten times during the last decade (Brzovic, Miller, and Lagos, 2001).

Air pollution is one of the main targets of this increasing public and private expenditure, particularly in Santiago – the capital city of Chile that houses over one-third of the population. Geographic and climate variables – in

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Wilcoxen, 1993; Li and Rose, 1995; or Rose *et al*., 1998. Energy issues are analysed in Piggot, Whalley, and Wigle, 1992; Goulder, 1993; Rose, Schluter, and Wiese, 1995. Natural resources allocation or management is dealt in Robinson and Gelhar, 1995; Mukherjee, 1996. Models focused on the evaluation of the economic impacts of specific environmental regulations, as the Clean Air Bill in the USA, or regarding environmental instruments include Jorgenson and Wilcoxen, 1990; Hazilla and Kopp, 1990.

[6] Annual average rates of exchange were used for calculations: 1US$ = 508,78$ in 1999, and 539,49$ in 2000.

particular thermal inversion that results in extremely high pollution concentrations in winter, together with significant emissions from transport – are the main factors behind air pollution in this city. Since 1990, two decontamination plans have been applied in Santiago[7] both aimed at reducing PM-10 emissions. They include, among many other measures, the elimination of 3,000 highly polluting buses, the incorporation of natural gas in the productive process of fixed sources, and introduction of catalytic converters in all new vehicles (as a result 50 per cent of cars in Santiago in 1999 have converters). As a result important reductions in PM-10 and PM-2.5 (23 per cent and 46 per cent respectively) have been achieved compared to 1989. Nevertheless, in 1999 there were 14 environmental pre-emergency events, the maximum for the 1990s, and one emergency event was declared (table 1). It is estimated that emissions must be reduced to half current levels to reach the desired air quality standards.

A new plan is being developed to propose the measures to be applied; however it is estimated that the measures being considered will not achieve the desired results. Hope is being put on the application of tradable emission permits – an economic instrument that, from a static perspective, is identical to the application of emission taxes.[8]

Other problem areas include poor air quality in Concepción–Talcahuano from steel, petroleum, fishmeal, paper, and pulp industries and high levels of ground-level ozone in Valparaiso–Viña del Mar. In Talcahuano an environmental recovery plan is operating and air monitoring systems are being established in several cities to identify saturated zones. Table 2 summarizes air quality problems by region.

The biggest threat to health from air pollution comes from fine particles. Studies indicate that there are significant effects on human health. For this reason, several territories have been declared 'saturated areas' for specific pollutants as can be observed in table 3.

Finally, other problems related to air are noise in the city of Santiago and bad smells surrounding fish meal and pulp and paper industries as well as dumping grounds.

In summary, in the last decade significant efforts have been undertaken to identify the main problem areas and to initiate decontamination efforts in Chile. In Santiago emissions of particulates and many gases must be

Table 1. *Santiago environmental situations in the 1990s*

Year	*Pre-emergency*	*Emergency*	*Year*	*Pre-emergency*	*Emergency*
1990	11	2	**1995**	2	0
1991	9	2	**1996**	6	0
1992	14	2	**1997**	13	0
1993	8	0	**1998**	12	1
1994	3	0	**1999**	14	1

Source: Metropolitan Health Service of Environment www.sesma.cl

[7] See O'Ryan and Larraguibel (2000).

[8] If uncertainty is not considered (Weitzman, 1974), nor monitoring and enforcement difficulties (Montero, 2000).

Table 2. *Air quality problems by region*

Pollutant	*Source*	*Affected area*
PM-10	Copper smelting Petroleum refinery Cement production Diesel motors	II, III, VI regions V region V region SMA
SO_2	Copper smelting Petroleum refinery Cement production	II, III, VI regions V region V region
Ozone	Copper smelting Petroleum refinery Cement production Vehicles	V region V region V region SMA
Sulfhydric acid	Pulp and paper Fishmeal industry	VII, VIII and IX regions VIII region
Trimethylamine	Fishmeal industry	VIII region
CO and CO_2	Vehicles	SMA
NO_x	Vehicles	SMA

Source: CONAMA-Univ de Talca-Univ. de Concepción, 'Seminario Taller: Analisis de Aplicabilidad y Propuesta de Instrumentos Tributarios para la Política Ambiental', March 1998.

Table 3. *Saturated areas in Chile*

Region	*Territory*	*Saturated of:*	*Year*
II	Maria Elena, Pedro de Valdivia Areas	PM-10	1993
II	Chuquicamata Camp	SO_2, PM-10	1991
II	Potrerillos Smelter Area	SO_2, PM-10	1997
III	Hernán Videla Smelter Area	SO_2	1993
V	Chagres Village	Latent SO_2	1991
V	Ventanas Smelter Area	SO_2, PM-10	1993
VI	Caletones Area	SO_2, PM-10	1994
RM	Santiago Metropolitan Area	PM-10, CO_2, O_3, latent NOx	1996

Source: CONAMA (1997, 1998).

reduced to by 50 per cent to reach air quality goals, and in other cities similar or stronger reductions are required.

3. Taxes as an environmental instrument

Theory suggests that to attain optimal[9] pollution levels, emission fees or tradable emission permits should be used. Usually authorities substitute more easily applicable emission limits for pollution fees, both because public institutions are more used to them and because they are more pol-

[9] Optimal is used in the sense of cost-effective in this paper, not the social optimum.

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itically acceptable. Even so, green taxes have been used in many parts of the world:

(i) Taxes on emissions or effluents (a charge on the quantity and/or quality of air pollutants) are applied in China, Poland, France, Sweden, etc.
(ii) Charges to activities causing environmental damage (charges to the user of contaminating processes or administrative charges on operations) are applied in Singapore, Denmark, Sweden, etc.
(iii) Charges to products (differentiated taxes that put a heavier burden on polluting products) are used in The Netherlands, Sweden, Norway, etc.

However it is common to use fees to collect money rather than to encourage a direct reduction in pollution. Additionally tradable permits – a policy instrument symmetric to taxes based on quantity restrictions – are being used in an increasing number of urban contexts for gas emissions, for acid rain problems, and are being discussed for greenhouse gas emissions.

In Chile environmental taxes have not been applied at all. However there are important taxes applied to fuels. Since changes in these taxes will be discussed in section 5, we present the tax structure in Chile for 1993–1996 in table 4.

First category taxes apply to retained corporate profits. Secondary tax applies to salaries, wages, and pensions when these are the only source of income. Global complementary tax applies to global income, however there are credits for corporate and first category taxes. The additional tax

Table 4. *Tax structure in Chile in percentage of total government revenue (1993–1996)*

Tax	*1993*	*1994*	*1995*	*1996*
Income taxes	**20.1**	**19.4**	**18.1**	**19.4**
First category tax	10.2	10.0	9.9	10.7
Second category Tax	5.0	5.0	4.4	4.6
Global complementary tax	2.6	2.7	2.3	2.1
Additional tax	3.2	3.3	3.0	3.1
40% tax DL 2398	0.3	0.7	0.6	0.7
Others	−1.1	−2.2	−2.0	−1.9
Codelco	**6.5**	**10.6**	**13.6**	**11.3**
Social security	**7.3**	**6.9**	**6.3**	**6.4**
VAT	**41.3**	**40.4**	**38.7**	**39.4**
Excises	**9.1**	**8.7**	**8.7**	**9.1**
Tobacco products	2.9	2.8	2.7	2.7
Petroleum products	6.2	5.9	6.0	6.4
Civil registration	**2.9**	**3.0**	**2.8**	**3.1**
Trade taxes	**11.0**	**9.5**	**9.7**	**9.8**
Other	**1.7**	**1.6**	**1.9**	**1.5**
TOTAL	**100.0**	**100.0**	**100.0**	**100.0**

Source: Zee (1998).

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applies to distributed and remitted profits to non-residents. The 40 per cent tax applies to state-owned enterprises.

4. A CGE framework to evaluate environmental policies: the ECOGEM–Chile model

There are few applications of computable general equilibrium models for policy evaluations in Chile.[10] At the beginning of the nineties the OECD developed a general equilibrium model that has been applied to different countries across the world. Beghin *et al*. (1996) present the only environmental application for Chile, analyzing the environmental impact of carrying out environmental policy, trade liberalization and trade agreements by means of a dynamic application of the model. This same multi-regional model – which includes 26 regions and 72 productive sectors – has been adapted in this paper improving some specific equations and in particular updating the data. The rest of the section presents the general equilibrium model developed for Chile – the ECOGEM–Chile model – to evaluate environmental policies. The specific characteristics of the model are presented first, then the emission reduction options considered, and finally the data used.

4.1. The model[11]

The ECOGEM-Chile model is a static model characterized by sector multiplicity, occupational category differentiation, income quintiles, multiple trade partners, and specified productive factors, among other features. It is basically a neoclassic model, which is savings driven. An important characteristic is that it incorporates energy-input substitution as a way to reduce emissions, since emissions are related to the use of different inputs and not only to production levels as is usually considered in these models.

The main equations are related to the production, consumption, and external sectors. For a better understanding of these equations, the main indexes that will be used in the model's equations are listed below:

i, j Productive sectors or activities
l Types of work or occupational categories
h Household income groups (quintiles)
g Public spending categories
f Final demand spending categories

[10] Two models have been developed to analyze the effect of changes in tariff policies: Coeymans and Larraín (1994) and Harrison, Rutherford, and Tarr (1997). In these two models similar techniques are used to analyze the effects of Chile signing different trade agreements. A third study, Ruiz and Yarur (1990), uses data from the 1977 I/O matrix, to analyze the effects in the economy of the change in different taxes. The most recent application, is the work of Bussolo, Mizala, and Romaguera (1998), this study tries to analyze the effects of trade agreements on the labor market. They use for this the OECD model discussed following.

[11] The ECOGEM-Chile model has been adapted by ASD/IPA and CAE of the University of Chile from the one generated at the OECD by Beghin, Dessus, Roland-Holst, and van der Mensbrugghe (1996).

r Trade partners
p Different types of pollutants

Production: Production is modeled by the CES/CET nested functions (i.e. constant elasticity of substitution – transformation). If constant returns to scale are assumed, each sector produces while minimizing costs

$$\min PKEL_i KEL_i + PABND_i ABND_i$$

$$\text{s.t.}$$

$$Xp_i = [a_{kel,i} KEL_i^{\rho_i^p} + a_{abnd,i} ABND_i^{\rho_i^p}]^{1/\rho_i^p}$$

In the tree's first level, decisions are made through a CES function to choose from a non-energy-producing intermediate input basket and a factor basket (i.e. capital and labor) and energy producing inputs (KEL). In order to obtain the non-energy-producing intermediate input basket a Leontieff-type function is assumed. On the factors' side, the capital–energy basket and labor is split through a new CES function, and then energy is separated from capital, always assuming CES functions for substitution both between and within factors (types of labor, energy, and capital).

Income distribution: Production-generated income is allocated in the form of wages, capital returns, and taxes between the domestic economy, the government, and the domestic and international financial institutions.

Consumption: Households distribute their income between saving and consumption through an ELES utility function (Extended Linear Expenditure System).[12] This function also incorporates the minimum subsistence consumption as independent from the level of income

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

$$\text{subject to } \sum_{i=1}^{n} PC_i C_i + S = YD$$

$$\text{and } \sum_{i=1}^{n} \mu_i + \mu_s = 1$$

Where U stands for the consumer's utility; C_i is the consumption of good i; θ is the subsistence consumption; S, saving; cpi, the price of savings; and μ the consumption marginal propensity to consume each good and to save.

Other final demands: Once the intermediate demands and household demands are defined, there is only the rest of the final demands to include, i.e. investment, government spending and trade margins. Other final demands of each item are defined as a fixed share of total final demand.

[12] The way in which savings are included (divided by a price index of the other goods) partially neutralizes the substitution between consumption and savings, because the savings' price is a weighted price of all the other goods. In this sense, savings represent future consumption.

Public finances: regarding public finances, there are different types of taxes and transfers. The following are defined in the model: labor tax (differentiated by occupational category), taxes on firms, on income (differentiated by quintile), all of them direct. Also import tariffs and subsidies are defined, together with export taxes and subsidies (by sector) and a value added tax VAT (for domestic and imported goods, and by sector).

As a closure condition for public finances, the model allows two alternatives: first, government spending is defined as fixed and equal to the original level previous to any simulation, allowing it to adjust through some tax or government transfer. Second, government spending is allowed to vary, while taxes and transfers are kept fixed. The first option has been used here.

Foreign sector: to incorporate the foreign sector, the Armington assumption is used to break down goods by place of origin, allowing imperfect substitution between domestic and imported goods and services. As with production, there is a CES function that allows substitution between the imported and the domestic basket. In turn, the domestic supply gets a similar treatment as demand, now including a CET function to distinguish the domestic market from exports.

For imports

$$\min PDXD + PMXM$$

$$\text{subject to } XA = [a_d XD^{\rho} + a_m XM^{\rho}]^{1/\rho}$$

Where *PD* and *PM* are the prices of domestic and imported goods, while *XD* and *XM* are the respective amounts. *XA* stands for the good made up of both or the 'Armington good'. Parameter ρ is the substitution elasticity between both goods.

For exports

$$\max PD\ XD + PE\ ES$$

$$\text{subject to } XP = [\gamma_d XD + \gamma_e ES^{\lambda}]^{1/\lambda}$$

Where *PE* is the price of the exported good and *ES* is the respective amount. *XP* is the sector's total production. Parameter λ is the substitution elasticity between both goods.

Factor market equilibrium conditions: to achieve labor market equilibrium, labor supply and demand are made equal for each occupational category, where supply is determined on the basis of real wages. As for the capital market, a single type of capital is assumed to exist, which may or may not have sector mobility depending in the imposed elasticity; for this case no capital mobility between sectors is assumed.

It is worth noting that long-term elasticity's has been assumed for the substitution between the factor nest and non-energy-producing inputs, as well as for the CES between capital–energy and labor, between capital and energy, and for the various energy-producing sectors. This assumption allows greater substitution between factors and is considered more realistic from a medium-term viewpoint.

Closure conditions: the closure condition for the public sector has already been anticipated, i.e. government spending is fixed. Also, as is usual in these models, the value of the demand for private investment must equal the economy's net aggregate saving (from firms, households, government and net flows from abroad). The last closure rule refers to balance of payment equilibrium. This equation will be introduced into the model through Walras' Law.

Parameters of the model: The model allows varying the degrees of capital mobility among sectors and the substitution elasticities among inputs/production factors. More flexible parameters represent more flexible adjustments. The simulations presented in section V were done without capital mobility and with long-term substitution elasticities, which together represent a short/medium-term adjustment process. Specific parameters and sensitivity analysis are presented in annex A.

4.2. Emission reduction within the model

The model allows three possibilities to reduce emissions of pollutants in the economy. The first, used traditionally in general equilibrium models, is the reduction in the production of the most polluting sectors. A second option is the substitution of the more polluting energy-producing inputs in the productive process or in consumption for less contaminating energy inputs. The third allows reducing by using 'end of pipe' technologies (e.g. filters, treatment plants, and the like). This latter possibility is in its experimental stage and will not be included in the results of our simulations.[13]

Production reduction: In this case, introducing a tax on emissions generates an increase in production costs, which in turn causes – *ceteris paribus* – an increase in the price of the good produced by the polluting industry (that pays for the tax). Thus it becomes less competitive at both the national and international level and reduces the amount demanded for the good and also production, at least in the long run. In case of an environmental regulation that sets a limit for emissions, the company will be forced to reduce its level of production.

Basically, this possibility comes from making prices endogenous in the general equilibrium model and the possibility of reallocating factors and resources among the various productive sectors, substitution between different goods for final demand or substitution between the domestic and the foreign markets (CES/ELES/CET-Armington functions, respectively).

Substitution between inputs: the use of each type of input in either the production or the consumption by final demand causes a certain level of emissions independently of the productive process. Therefore, another

[13] Not included in the model is the possibility of technological change – from investment processes based on relative returns – towards new supposedly less polluting technologies, because it would be necessary to use a dynamic model. However it is possible to change substitution elasticities to simulate more flexible technologies to less polluting processes. Also environmental quality as a good for which there is a willingness to pay, and therefore alters consumption decisions relative to the rest of the goods and their equilibrium prices, has not been considered.

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way to reduce emissions is to substitute less polluting inputs for the more polluting ones. In case of a tax on emissions, the costs associated to the use of that input are being indirectly increased, and thus their relative use is being made costlier and its substitution encouraged.

In case a new emission regulation is set, a constraint is introduced to optimization both in the domestic economies and in firms. In this case, to continue using the same volume of polluting inputs leads to a below-optimal situation that converges towards the original optimum to the extent that substitution occurs towards less or non-contaminating inputs.

The model basically differentiates between energy-producing and non-energy-producing inputs. Non-energy-producing ones are used in the production function with fixed coefficients. Substitution between energy-producing inputs or between these and other productive factors (capital and labor) is determined by CES functions nested within the production function.

Energy-producing inputs (i.e. coal, petrogas, petroref, electricity, and gas) are associated to the emission of 13 types of pollutants (not all of them discharged by the energy-producing inputs) through emission factors. These emission factors link the use of each monetary unit spent in the input to the amount of emissions of each pollutant in physical units. Total volume of emissions in the economy for each type of pollutant is therefore determined by

$$E_p = \sum_i \upsilon_i^p \cdot XP_i + \sum_i \pi_i^p \left(\sum_j XAp_{ij} + \sum_h XAc_{ih} + \sum_f XAFD_f^i \right)$$

This is the sum of all the emissions of the pollutant '*p*' caused by all the productive sectors '*i,j*' of the input–output matrix generated in their productive processes *per se*, independently of the emissions associated to the use of polluting inputs, in addition to all the emissions derived from the use of polluting intermediate inputs[14] in the productive processes of all the sectors, in their consumption by households '*h*' and by other components of the final demand '*f*'.

4.3. The data

As in any general equilibrium model applied, the main source of information is the Chilean social accounting matrix. This matrix was built for this application based on the recently released input/ouput matrix for 1996 (Banco Central de Chile, 2001).

The wider social accounting matrix for Chile, used preliminarily, was reduced in order to enable a better mathematical convergence, without diminishing its capacity to analyze relevant political scenarios. The original 73 economic sectors of the input–output matrix were aggregated to 18 (see annex B). Labor factor was divided into skilled and unskilled. It also includes the foreign sector and disaggregates household income into five quintiles. The matrix is measured in billions of pesos of 1996.

As for the income, substitution, and other elasticity's used, long-term elasticity's used in the relevant international literature have been used,

[14] Not only energy producing.

thus providing more flexibility to the adjustment process and more realistic results. However, investment and capital accumulation processes as a function of relative returns may not be incorporated, and long-term elasticities only minimize this flaw.

Finally, there are two types of emission coefficients. One comes from inputs used and the other is related to the productive processes. On the other hand, there are five types of pollutants identified, namely: SO_2, NO_2, VOC (volatile organic compounds), CO and PM-10. Emission coefficients are obtained from Dessus, Roland-Holst, and van der Mensbrugghe (1994).

5. Environmental, social and economic impacts of improving air quality in Chile

This section presents the results of applying a general equilibrium approach to evaluate environmental policies in Chile. The CGE framework allows assessing the environmental impacts but also the economic and social impacts. These latter include macroeconomic impacts (on GNP and employment for example), sectoral impacts, i.e. sectors that win, increasing the value of their production, and those that lose, and distributive impacts. The direction and magnitude of change are determined, providing better information to policy makers for their decisions. Thus, a systematic approach to evaluate impacts of environmental policy is developed.

Additionally, since the policy instruments considered (increase in taxes) would allow government revenues to increase, reductions in other taxes are considered that exactly offset this increase. As will be seen, the decision on which taxes are applied to reduce emissions and which to offset the increase in government revenues, determine significantly the final impact of the emission reduction on the economy, the sectors affected and the income distribution.

The first section presents the results of applying an emission tax on PM-10 to reduce emissions by 10 per cent. The increase in government revenues is offset by reducing two taxes and the impact of each option is analyzed in detail. The second section assesses the economic, distributive and sectoral impacts associated to the same emission reduction goal, but using a different instrument, a tax on fuels. Finally the third section assesses the impacts of applying an emission tax that would allow a significant 50 per cent reduction in emissions, as required in Santiago, and other parts of the country.

Evaluating the impact of emission taxes is necessary for Chile since currently the application of marketable permits – an instrument symmetric to taxes – is being proposed for urban contexts. The results obtained of simulating an emission tax will be those to be expected if marketable permits are successfully implemented. Moreover, the assessment of a suboptimal fuel tax will allow concluding whether the efficiency losses are significant, together with the changes in the winners and losers of applying this instrument. Finally, the possibility of substituting distorting taxes fort other taxes is not a minor issue in Chile since strong political coalitions favor reducing taxes.

5.1. Taxes on PM-10 emissions

The ECOGEM–Chile model has been applied to assess the impact of an emission tax that imposes a 10 per cent reduction in PM-10 emissions. To maintain public savings constant, two offsetting taxes are used, reduction in corporate taxes and in VAT. These taxes were chosen because they are the first two contributors in total government income (see table 4). In summary, two policies are simulated: environmental taxation compensated by VAT reduction, and environmental taxation compensated by corporate tax decrease.

The results of the simulation are summarized in table 5. These include the impact on the main macroeconomic variables, on the three sectors most negatively affected and the three most positively affected, on each of the income quintiles, and on emissions of five air pollutants.

From a macroeconomic perspective there are low impacts on real GDP, investment, and aggregate consumption. However, negative impacts on exports and imports are higher. The offsetting instrument used matters little here. The external sector falls by the same amount in both cases, affecting both imports and exports due to higher taxes affecting domestic

Table 5. *Reduction of 10 per cent of PM-10 emissions*

	Compensatory tax			
Policy impacts	*Corporate tax*		*VAT*	
Macro				
Real GDP	−0.2	%	−0.2	%
Investment	0.0	%	−0.1	%
Consumption	−0.3	%	−0.2	%
Exports	−1.1	%	−1.1	%
Imports	−1.0	%	−1.0	%
Sectoral				
Electricity	0.4	%	0.6	%
Textiles	0.1	%	0.6	%
Hydraulic	0.1	%	0.3	%
Other Transports	−2.4	%	−2.2	%
Oil Extraction	−4.7	%	−4.7	%
Oil Refinery	−10.6	%	−10.6	%
Distributive*				
I Quintile	−0.4	%	−0.2	%
II Quintile	−0.4	%	−0.2	%
III Quintile	−0.3	%	−0.2	%
IV Quintile	−0.3	%	−0.2	%
V Quintile	−0.3	%	−0.2	%
Environmental				
Emissions SO_2	−10.8	%	−10.9	%
Emissions NO_2	−10.7	%	−10.7	%
Emissions CO	−3.7	%	−3.6	%
Emissions VOC	−1.2	%	−1.0	%
Emissions PM-10	−10.0	%	−10.0	%

Note: * Real disposable income (quintile I is the poorer).

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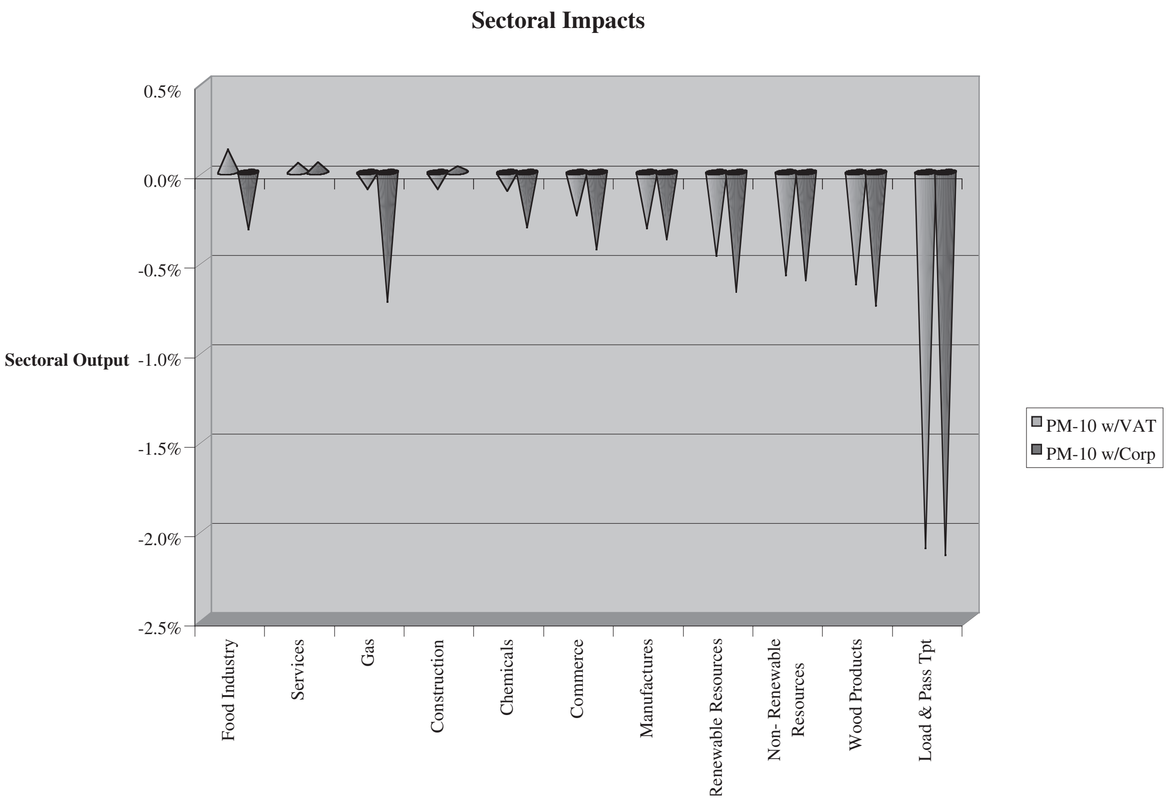

Figure 1. *Sectoral impact of taxing emissions of PM-10, compensating with a reduction of VAT and corporate taxes*

prices of all goods, domestic imports and exports. The overall impact of both policies is a slight reduction in GDP.

Regarding the sectors, there are many similarities between winners and losers under both offsetting instruments. In general, the most penalized sectors are those directly linked to the production of petroleum-derived fuels, or those sectors that require these fuels as principal inputs. However, alternative energy sectors (electricity and hydraulic), plus the textile sector are the 'winning' sectors here. The latter have greater positive impacts when VAT is reduced due to their importance in household consumption.

Transport is the most affected non-energy-producing sector. In particular, the 'Other Transport' sector which includes basically air, sea, and railroad transport. From figure 1, the remaining sectors are not affected significantly. However, it is interesting to note that the offsetting instrument matters for many of them. For example, the construction sector is negatively affected when VAT is reduced, and positively if environmental taxes are offset with corporate taxes. The opposite is true for the food industry.

As for income distribution, the results systematically show that to offset environmental taxes with corporate taxes is more regressive than doing so with VAT (table 5). Under both policies, the real disposable income of all the quintiles decreases, however when the corporate tax is reduced the lower quintiles lose more. In any case, since variations are never as large as 1 per cent, considering previous exercises we agree with the thesis of Engel, Galetovic, and Raddatz (1998) whereby changes in the Chilean tax structure has little direct effect on income distribution.

Finally, the taxes applied are successful in reducing PM-10 emissions by 10 per cent. Moreover they allow reducing simultaneously the emissions of NO_2 and SO_2 even more than PM-10 emissions as a result of fuel switching and reduction of production in the more polluting sectors.

A sensitivity analysis of the key parameters of the model – capital mobility and substitution elasticities in the production function – shows that the results hold in general. However, with less rigidity in the adjustments (higher capital mobility and long-term substitution elasticities), the impacts are more significant on affected sectors (see annex A).

In summary, the general economic impacts of a 10 per cent reduction in emissions are low, however there are sectors that are much more strongly affected than others. In particular losers see the reduction of the value of their production fall significantly more (in percentage) than the percentage increase that winners observe. Distributive impacts are slightly negative for all quintiles, however the degree of regressiveness depends on the offsetting instrument applied. Even though both policies lead to the same macroeconomic impacts, the channels are different. Noticing these differences allows building complementary policies in order to enhance positive effects and reduce negative ones.

5.2. Fuel taxes to reduce emissions 10 per cent

Fuel taxes are currently applied in Chile and are a good candidate to be increased to reduce emissions. Even though strong lobby groups – particularly in the transport sector – oppose this possibility, it is seen as a feasible option, particularly if other taxes are reduced to offset the increase in government revenues. To make this simulation comparable to the previous one, the fuel tax was raised until a 10 per cent reduction in PM-10 emissions was achieved. An enormous 150 per cent increase in the tax rate on fuels was necessary for this. Also, as in the previous section, real public saving was kept at the reference level, offsetting the tax increase by a reduction in VAT. The results obtained are presented in table 6.

Macroeconomic impacts are slightly worse when applying a fuel tax, especially consumption. This is to be expected since there are some efficiency losses associated to this suboptimal instrument.

There are important sectoral differences however. Sectors related with fuel production, transformation, and sale suffer this tax more intensely and their sectoral output is reduced by 70 per cent more than under an emission tax. The three sectors that most gain are still the same, however the gains are slightly lower. Also distributive impacts are quite different and higher in the case of a fuel tax. In effect, taxing fuels has a larger negative impact on all households due to high fuel consumption in the consumers' budget.

Table 6. *Increase in the fuel tax by 150 per cent vs tax on PM-10, offset by VAT*

	Simulation			
Policy Impacts	*Fuel Tax*		*PM-10 Tax*	
Macro				
Real GDP	−0.3	%	−0.2	%
Investment	−0.1	%	−0.1	%
Consumption	−0.4	%	−0.2	%
Exports	−1.1	%	−1.1	%
Imports	−1.0	%	−1.0	%
Sectoral				
Electricity	0.5	%	0.6	%
Textiles	0.3	%	0.6	%
Hydraulic	0.2	%	0.3	%
Other Transports	−2.1	%	−2.2	%
Oil Extraction	−7.5	%	−4.7	%
Oil Refinery	−17.5	%	−10.6	%
Distributive*				
I Quintile	−0.3	%	−0.2	%
II Quintile	−0.4	%	−0.2	%
III Quintile	−0.4	%	−0.2	%
IV Quintile	−0.4	%	−0.2	%
V Quintile	−0.4	%	−0.2	%
Environmental				
Emissions SO_2	−10.9	%	−10.9	%
Emissions NO_2	−10.8	%	−10.7	%
Emissions CO	−3.6	%	−3.6	%
Emissions VOC	−1.8	%	−1.0	%
Emissions PM-10	−10.0	%	−10.0	%

Note: * Real disposable income (quintile I is the poorer).

In general, the economic, distributive and environmental impacts, suggest that taxing fuels is considerably less desirable than taxing PM-10 emissions directly.

5.3. Impacts of reducing PM-10 emissions in 50 per cent

As mentioned earlier, Santiago and other urban locations require a 50 per cent reduction in emission in order to reach acceptable air quality standards. We have also simulated this possibility: a 50 per cent reduction of total emissions in the country. Currently, policies aimed in this direction are being taken very slowly since it is feared that such a reduction would be a very big shock to the economy.

The results confirm this fear. The impact on GNP is significant. Reducing emissions by 50 per cent shocks the whole economy reducing GNP by 1.5 per cent. Moreover, the absence of capital mobility prevents optimal resources allocations among sectors. Therefore, macro-costs are high. At a sectoral level, polluters now have to internalize much bigger penalties; and since capital is not mobile among sectors, intra-sectoral factors/inputs recomposition must be dramatic. This affects relatively more labor income which in turn affects more significantly those more dependent on it.

Table 7. *Tax on PM-10 emissions to reduce them in 50 per cent offset by VAT*

Simulation *Policy Impacts*	*Impacts*	
Macro		
Real GDP	−1.5	%
Investment	−1.2	%
Consumption	−1.7	%
Exports	−5.8	%
Imports	−5.3	%
Sectoral		
Electricity	3.1	%
Textiles	2.0	%
Hydraulic	1.1	%
Other Transports	−12.9	%
Oil Extraction	−24.6	%
Oil Refinery	−54.8	%
Distributive*		
I Quintile	−2.3	%
II Quintile	−2.3	%
III Quintile	−2.3	%
IV Quintile	−2.2	%
V Quintile	−1.2	%
Environmental		
Emissions SO_2	−54.4	%
Emissions NO_2	−53.7	%
Emissions CO	−16.6	%
Emissions VOC	−5.9	%
Emissions PM-10	−50.0	%

Note: * Real disposable income (quintile I is the poorer).

Table 8. *Changes in tax rates when emissions are reduced*

Tax	*Reduction of*	*Δ Tax rate (%)*
PM-10 Emissions (10%)	Corporate tax	−14.7
	VAT	−5.1
Fuel	VAT	−3.1
PM-10 emissions (50%)	VAT	−16.3

Consequently, an important difference with the more modest reduction in emissions is in the distributive impact. Even though all quintiles lose, the poorer lose significantly more. In other words, environmental policies turn out to be more regressive when higher emission reductions are required. This is explained by the fact that the intra-sectoral adjustment pressures more on the labor side, affecting wages relatively more, therefore impacting quintiles that depend basically on labor income.

Finally, even though the 'winning' and 'losing' sectors are basically the same ones, the impact on each is significantly higher. Reducing emissions five times more results in a reduction three times higher in the value of the output of the most affected sectors.

The results of the simulation suggest that the impacts would be significant and that the step-by-step policy currently applied by policy makers is warranted.

5.4. Impact on the tax system

Finally, it is interesting to examine whether the impact of an environmental tax warrants a small or large reduction in each of the offsetting taxes. Table 8 presents the required tax cuts.

If the government wants to reduce emissions by 10 per cent through a direct tax it can reduce corporate taxes by 15 per cent. This is a fairly significant amount. This opens an interesting possibility for the government, since it can obtain private sector support for the measure promising this offsetting tax reduction. The offsetting reduction in VAT is comparatively low (5.1 per cent), allowing a reduction from the 18 per cent current rate to only 17 per cent. However, when 50 per cent PM-10 emission reductions are required, the reduction in VAT can reach a significant 16 per cent. This again increases the political acceptability of the reduction.

6. Conclusions

The ECOGEM–Chile model allows a multidimensional analysis (macro, sectoral, distributive and environmental) of environmental tax policies. The model also allows assessing complementary policies (offsetting taxes) to mitigate the negative consequences and enhance the positive ones.

Using the model, a systematic assessment of the impacts of both emission taxes and fuel taxes to reduce PM-10 emissions in Santiago has been undertaken. In order to maintain real public savings constant, corporate taxes and VAT reductions were chosen as alternative offsetting taxes. The following conclusions can be drawn as a result of reducing PM-10 emissions by 10 per cent:

(a) Macroeconomic impacts are negative, however not too significant, independently of the policy instrument applied.
(b) The winner and loser sectors suffer significantly asymmetric impacts. Losing sectors suffer severe impacts while winning sectors gain little.
(c) The magnitude of the impact on each sector depends heavily on the instrument used. The highest reduction in value of output (in oil refinery) reached 10 per cent of sectoral output when PM-10 emissions were taxed, and more than 20 per cent when fuels were taxed. On the other hand, the most favored sectors were water (when PM-10 emissions were taxed) and gas (when a fuel tax was applied), increasing their output value by 3.3 per cent and 2.4 per cent, respectively.
(d) Across the board offsetting taxes, if adequately chosen, can significantly reduce regressive impacts. However they do not affect the macroeconomic or sectoral impacts. Offsetting with VAT is generally less regressive than a cut on corporate taxes.
(e) Authorities can also consider significant cuts in corporate taxes (up to 15 per cent) as an alternative. Even though more regressive, they may make the application of environmental policies more palatable to the private sector.

When a significant 50 per cent reduction in emissions is considered, the results are more extreme. The impact on GNP is significant, falling by 1.5 per cent. The environmental policies turn out to be more regressive due to a deeper impact on labor income of the adjustment process. The impact on wining and losing sectors is significantly higher. The highest losing sector sees the value of its output fall by over 50 per cent. All these impacts strongly suggest a step-by-step environmental policy.

In summary, applying a CGE framework enables policy makers to obtain important insights for environmental policy in Chile. This allows an integrated analysis of policy implications, taking into account the most relevant relationships. The results justify tax reforms aimed at taxing 'bads', such as PM-10 emissions. Some sectors have been identified as losing, but others as gaining. Distributive and sectoral impacts can be ameliorated designing adequate offsetting and complementary policies. Additionally, a gradual reduction process seems warranted considering that macroeconomic impacts can be significant if important emission reductions are required.

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Annex A: Sensitivity analysis

In CGE models, parameters and elasticities can be determining elements in the results. They can also be used as a tool for a broader policy analysis. Their modification allows simulating indirectly a kind of temporal process of adjustment. In this annex, some assumptions on parameters/elasticities are modified and the results are discussed.

The policy exercise chosen, refers to the application of an environmental tax to reach a 10 per cent reduction in PM-10 emissions, when VAT is the offsetting tax. Capital mobility parameters and substitution elasticities among inputs/factors, included in the nested production function, were modified.

The cases considered include:

WMLT: Without inter-sectoral capital mobility and with long-term substitution elasticities. Short/medium-term adjustment process.
MST: With inter-sectoral capital mobility and with short-term substitution elasticities. Medium-term adjustment process.
MLT: With inter-sectoral capital mobility and with long-term substitution elasticities. Long-term adjustment process.

The results are presented in table A. The differences among each are not too substantial.

Extreme cases of capital mobility (capability to reassign productive capital – plant and equipment – within the economy), were simulated: with and without capital mobility within sectors. Total capital mobility can be associated with a long-term adjustment in which average profits and wages are equal among sectors. Therefore it reinforces inter-sectoral adjustment to policies. Without capital mobility, adjustments have an intra-sectoral orientation.

Regarding substitution elasticities, when the short-term is represented, they are: 0.01 between inputs and factors (capital–energy–labor), 0.12 between labor and capital–energy, 0.00 between capital and energy, and 0.25 among types of energy. Long-term elasticities are 0.50, 1.00, 0.80, and 2.00, respectively.

When the MST scenario is calibrated, adjustment tends to be intersectoral, without altering the internal structure (inputs and factors) in each sector, therefore 'winners' demand more capital but also more of the other factors/inputs until all sectoral rates of returns are equalized. Nevertheless, the economy's average rate of return should be less than the case in which long-term substitution elasticities are applied (MLT). In the latter, the whole economic system has more degrees of freedom to achieve the maximum rate of return, considering the new policy scenario – intra-sectoral adjustment is also allowed in the optimization process.

The WMLT scenario (used in the paper) allows adjustment in the interrelations among capital, labor, energy types, inputs inside the sectors, but

Table A. *10 per cent reduction of PM-10 emissions (sensitivity analysis)*

	Simulations		
Δ %	*WMLT*	*MST*	*MLT*
Macro			
Real GDP	−0.2	−0.1	−0.2
Investment	−0.1	−0.2	−0.1
Consumption	−0.2	−0.1	−0.2
Exports	−1.1	−1.3	−1.2
Imports	−1.0	−1.1	−1.1
Sectoral			
Electricity	0.6	1.0	2.3
Textiles	0.6	3.2	1.2
Hydraulic	0.3	2.2	0.8
Other Transports	−2.2	−9.3	−5.3
Oil Extraction	−4.7	−5.6	−5.5
Oil Refinery	−10.6	−12.1	−12.0
Distributive			
I Quintile	−0.2	0.0	−0.2
II Quintile	−0.2	−0.1	−0.2
III Quintile	−0.2	−0.1	−0.2
IV Quintile	−0.2	−0.2	−0.2
V Quintile	−0.2	−0.1	−0.2
Environmental			
Emissions SO_2	−10.9	−10.7	−10.8
Emissions NO_2	−10.7	−10.6	−10.6
Emissions CO	−3.6	−4.6	−4.6
Emissions VOC	−1.0	−0.5	−0.5
Emissions PM-10	−10.0	−10.0	−10.0

intersectorial adjustment is totally limited by an absence of capital mobility. Therefore, the sectors more affected by environmental taxation do not reduce their output as much – winners do not increase so much more – due to this restriction in the optimizing process. In conclusion, the sectoral adjustment is less traumatic, ceteris paribus; although, at an aggregated level, adjustment could be costlier. This case looks more realistic when a new policy or external shock is applied and the economic agents try to adapt without changing their normal activity.

Annex B: Agregation of economic activities in the model

Aggregated sectors used	*Reference to 1996 I–O Matrix*	*Description*
Renewable	1–5	Agriculture, fruit, livestock, forestry, fishing
Non-renewable	8, 9, 10	Copper, iron, other minerals
Oil and gas extraction	7	Extraction of crude petroleum and natural gas
Coal	6	Coal
Food	11–25	Slaughter, diary, conserves, sea food, oils, bakery, sugar, other foods, feedstock, drinks, wine and liquor, tobacco
Textile	26–29	Textile, clothes, leather, shoes
Wood	30, 31, 46	Wood products, furniture, pulp and paper
Chemicals	32, 34–38	Printing, chemicals, other chemicals, rubber, plastics, pottery, glass
Oil refinery	33	Refinery
Machinery	39–45, 47	Non-metalic minerals, basic metals, metalmechanics, non-electric machinery, electric machinery, transport materials, professional equipment, other manufactures
Electric	48	Electricity
Gas	49	Gas
Hydraulic	50	Hydraulic
Construction	51	Construction
Commerce	52–54	Commerce, restaurants, hotels
Road transport	56, 57	freight transport, passenger transport
Other Transport	55, 58–60	Railways, sea transport, air transport, other transport.
Services	61–73	Comunications, banks, insurance, rents, serv. to firms, house prop., public and private education, public and private health, entertainment, other entertainment, repair, other services , public adm.