GENERAL EQUILIBRIUM ANALYSIS OF A FUEL TAX INCREASE IN CHILE

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Achieving economic growth has been an important issue for over half a century. More recently, developed countries have incorporated the need for a more equitable and environmentally balanced growth. The complexity of modeling an economy with all its interrelations, agents, and sectors, however, has led to the common practice of studying economic, social, and environmental policies in isolated form, in a context of partial equilibrium. Unfortunately, many measures that affect the environment also have an impact on economic growth, poverty, employment, or income distribution. Consequently, a full understanding of either the effects of macroeconomic policies on the environment or the impact of environmental or welfare policies on macroeconomic variables can only be achieved through the use of models that include the complex interrelations between the diverse sectors and agents of the economy. Significant developments have been made in the last fifty years with regard to the concepts and, more fundamentally, the analytic and computational tools for implementing such models.

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In the 1960s, growth and, more generally, economic development formed the central objective of economic planning. In 1966, Kuznets emphasized that achieving modern economic growth and the so-called industrialization of developing countries would require introducing drastic and systematic changes in the production structures, along with changes in demand, employment, investment, and international trade. He further warned of the relevance of carefully examining the velocity and schedule for these changes. Accordingly, in-depth planning of the process of growth, with an appropriate level of detail and disaggregation, was deemed fundamental.

The systematic and structural nature of the economic changes, and the great speed with which they were applied, generated consequences that crudely revealed that production sectors, trade structures, and the different markets and their participating agents could not be considered, analyzed, or intervened independently. Production bottlenecks, excesses in sectoral supply, unsatisfied demand, inefficient resource allocation, and the dependence of national policies and structural adjustments on international events increased the necessity of developing multisectoral models with increasing disaggregation. These were required to provide a useful framework for understanding and planning the structural changes, stressing the interrelations and interdependencies among production sectors, markets, agents, and so forth in a setting of general equilibrium.

In this context, input-output models were initially the main tools employed by those in charge of economic planning. They allowed the analysis of the linkages between sectors and the use of productive factors, mainly capital and labor. They were also helpful in understanding the different components of final demand and the value added of each particular sector and in facilitating a systematic comparison of them. These models suffer from serious limitations, however, such as their inability to incorporate market mechanisms or optimization processes, their fixed coefficients that impose fixed relative prices, their poor substitution possibilities, and their lack of social and environmental variables. Nevertheless, they were used for these purposes, based on the incipient development of computer sciences and mathematical techniques.

In the 1970s, exclusive concern with growth and development goals began to be perceived as insufficient. The debate about the need to balance economic growth and environmental impacts entered strongly starting in 1972, when the Club of Rome published *The Limits to Growth* (Meadows and others, 1972). Those in charge of generating social and economic policies and economic agents in general had to incorporate new relevant variables into their decisionmaking process. Growth models increased in complexity, and the detailed definition of development strategies became even more necessary.

In 1987 the Brundtland Commission brought the concept of sustainable development into the mainstream discussion, defining it rather vaguely as development that "allows achieving the needs of the present generations without endangering future generations."[1] In practice, this definition has required that developing societies simultaneously meet economic, environmental, and social objectives for both the present and future generations (Pearce and Turner, 1990). Countrywide economic models therefore need to take into account a diversity of objectives associated with sustainable development. Economic objectives consider the need not only for economic growth, but also for increased equity and efficiency. Environmental objectives include concern about system integrity, bio-diversity, the capacity for assimilation, and global issues. Finally, social objectives encompass issues such as participation, social mobility, cultural identity, and institutional development. The debate on development continues with more or less conflicting positions, incorporating and trying to integrate economic and environmental variables in the most appropriate way.[2]

The complexity of the direct and indirect interrelations among economic, environmental, and social variables has increasingly called for models that allow the evaluation of policies that lead to sustainability. These models must take into account market mechanisms and optimizing behaviors, which determine the decisions of economic agents and the effectiveness of public policies. The prevailing economic paradigm requires eliminating the shortcomings of input-output models—such as the failure to incorporate price mechanisms—so they might contribute to planning processes.

Consequently, increasingly sophisticated policy analysis tools have been developed. These models are now able to capture the complex concept of sustainability, and they systematically and quantitatively analyze the evolution of the variables related to the three macroeconomic objectives of sustainability (namely, economic growth, equity, and environmental sustainability). In particular, applications based on computable general equilibrium (CGE) models were developed

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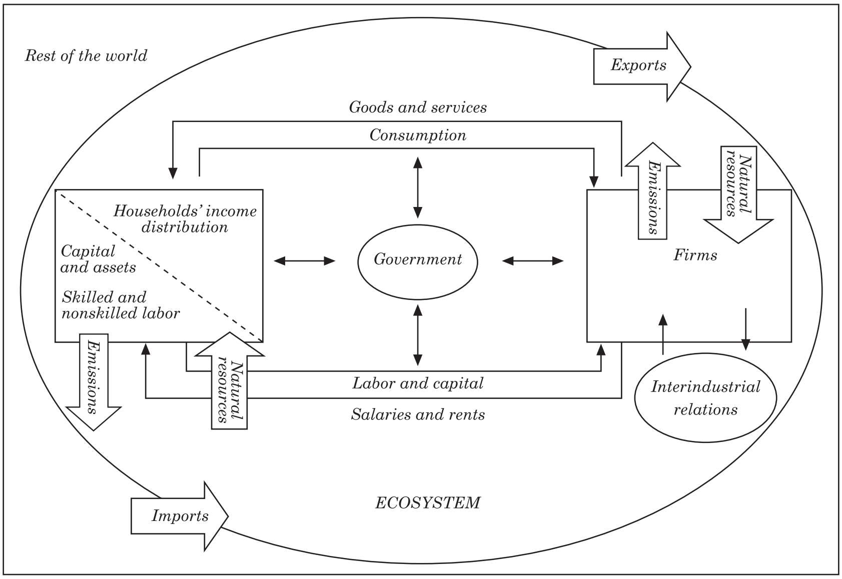
[1] See the *Brundtland Report*, also known as *Our Common Future*, presented by The World Commission on Environment and Development at the 42nd Session of the U.N. General Assembly (A/42/427, 4 August 1987).

[2] "Environmental Scares: Plenty of Gloom." *The Economist*, 20 December 1997; Dasgupta and Mäler (1998); Kneese (1998).

in the late 1970s and especially in the 1980s. These multisectoral models solve the limitations of the input-output models as evaluation instruments, representing the economy of a country more realistically by incorporating market mechanisms in the assignment of resources. They have also proved to be a useful instrument for describing the main relationships outlined and quantitatively evaluating ex ante the effects of different economic, social or environmental policies, in addition to the indirect side effects that in many cases evade the intuition.

Figure 1 schematically presents the relationships that can be modeled by means of a CGE model, based on the circular flow of the economy. It includes the main agents (that is, firms, households, and the government), flows of goods and services, payments to factors, international trade, and relationships with the environment. Each agent is modeled according to certain behavior assumptions; in particular it is common to assume optimizing producers (cost) and consumers (utility). Each market is modeled according to the specific reality of the economy—for instance, as a competitive or noncompetitive market or, in the case of the labor market, with or without full employment.

Figure 1. Circular Flow of the Economy



Source: Authors' elaboration.

These models simulate an economic Walrasian equilibrium by equating demand and supply in all markets, thereby obtaining equilibrium prices and quantities. A fundamental characteristic of the production sector in these models, as in the input-output models, is that it incorporates the demand for intermediate inputs, not just capital and labor. However, they differ from the rigid cost structure of the input-output models by allowing cost minimization by economic agents through substitution among production inputs (type and origin). The government sector is also modeled, as an agent that applies taxes, subsidies, and transfers.[3]

CGE models can be static or dynamic.[4] Static models are normally used for analyzing interrelations throughout the economy and the linkages among sectors and agents. Moreover, they focus on stabilization policies and contingency issues. Dynamic models focus more on forecasting issues related to growth patterns and development strategies. Nevertheless, static models can deal with different temporal frameworks by altering parameters and elasticities. There are tradeoffs between analysis and forecasting. Good analysis can be done using many sectors, but it requires many assumptions and a large number of parameters. Alternatively, it is hard to make realistic forecast estimations in a dynamic framework with many sectors, and simpler models are preferred.

The goal of this paper is to show the potential of CGE analysis as a tool for policy evaluation in Chile. The paper is organized as follows. Section 1 presents the basic features, assumptions, and equations of the ECOGEM-Chile model. Section 2 then describes the data used for simulating with the model. Section 3 presents the economic, social, and environmental impacts of an increase in fuel taxes of 100 percent. A second scenario is also analyzed, in which this environmental policy

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[3] CGE models generally do not include endogenous optimizing behavior or any objective function for the public sector, for both technical and ethical reasons. The budget restriction, including both expenditures/transfers and tax revenues, is the main component of the policy simulations, and it is modified exogenously to explore different policy implications. It is also a key element for the domestic closure rules of the model. On the other hand, tax structure and the distribution of expenditures (coming from the social accounting matrix) represent an elected government decision, which must symbolize the preference of the majority of voters in a democracy. Finally, a public utility function that allows the endogenous modification of the public expenditure decisions in response to, say, an external shock must be supported by an ethical discussion and by the generally accepted economic thinking before the empirical results of the simulations.

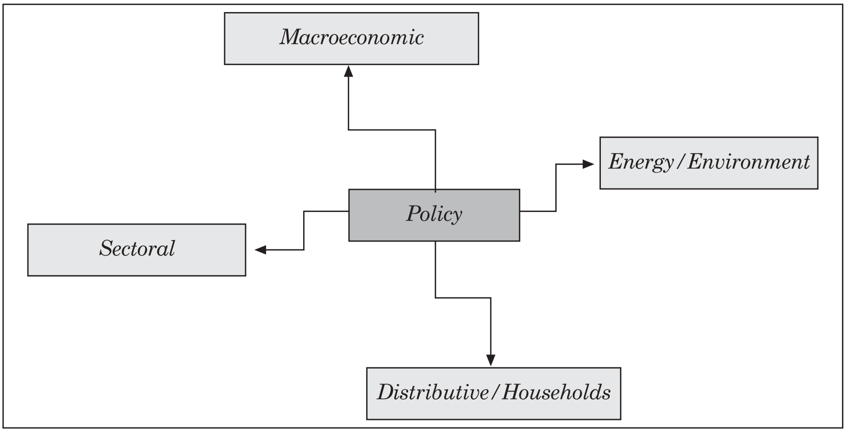
[4] For a review of theory and applications of CGE models, see O'Ryan, De Miguel, and Miller (2000).

is combined with a trade policy financed by the increased public revenues. Finally, section 4 presents our main conclusions.

1. THE ECOGEM-CHILE MODEL

The ECOGEM-Chile model was developed to analyze, in a general equilibrium framework, different policies and their impacts on the various agents in the economy. It is capable of analyzing the impacts of a given economic, social, or environmental policy on macroeconomic, sectoral, and social variables and the environment (figure 2).

Figure 2. ECOGEM-CHILE Analysis



Source: Authors' elaboration.

1.1 Basic Features of the ECOGEM-Chile Model

The CGE model developed for Chile is a static model with multiple sectors, labor differentiation, income-group differentiation, trade partners, and specified productive factors, among other features.[5] It is a neoclassical model, which is savings driven. It incorporates

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[5] The ECOGEM-Chile model was adapted by the Instituto de Asuntos Públicos (INAP) and the Centro de Economía Aplicada (CEA), both of the University of Chile, from a model developed by Beghin and others (1996) at the Organization for Economic Cooperation and Development (OECD). Basic features remain the same.

energy-input substitution to reduce emissions, as is common, because the emissions are related to the use of different inputs as well as to production and consumption levels.

The most important equations of the model are presented in this section, particularly those associated with environmental variables. The main indexes that will be used in the model's equations are as follows: production sectors or activities (*i, j*); types of work or occupational categories (*l*); household income quintiles (*h*); public spending categories (*g*); final demand spending categories (*f*); trade partners (*r*); and different types of pollutant (*p*).

Production structure

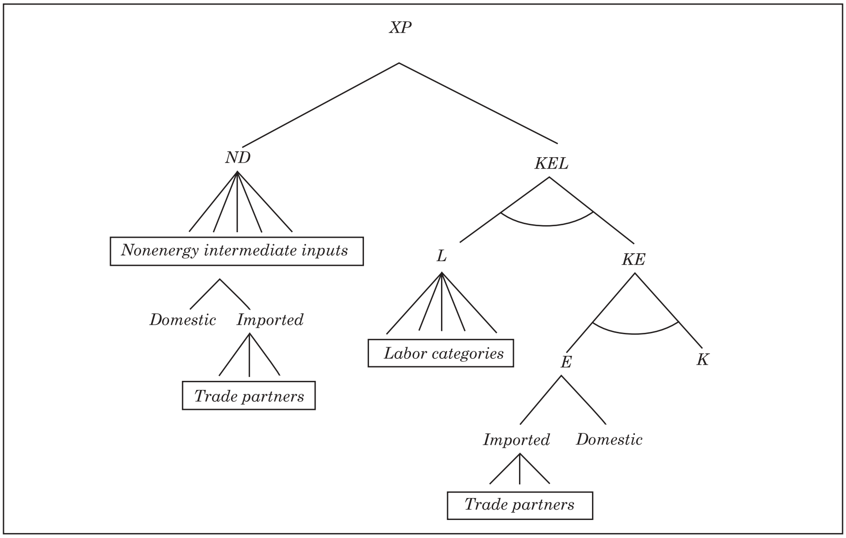
Production is modeled by CES/CET nested functions (that is, constant elasticity of substitution and constant elasticity of transformation). If constant returns to scale are assumed, each sector produces while minimizing costs:

$$\begin{aligned}&\text{min} \quad PKEL_i KEL_i + PND_i ND_i \\ &\text{s.t.} \quad XP_i = \left[\alpha_{KEL,i} KEL_i^{\sigma} + \alpha_{ND,i} ND_i^{\sigma}\right]^{1/\sigma},\end{aligned}$$

where *KEL* is a composite good of capital, energy, and labor; *PKEL* is the price of *KEL*; *ND* is a composite good of nonenergy intermediate inputs; *PND* is the price of *ND*; *XP* is total ouput; α is the share of input/factor use; and σ is the CES exponent related to the substitution elasticity.

Figure 3 presents the production function as a nested input/factor tree. 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 comprising capital, labor, and energy-producing inputs. To obtain the non-energy-producing intermediate input basket, a Leontieff function is assumed. On the factor side, a new CES function is used to split the elements into a capital-energy basket and labor and then to separate energy from capital, always assuming CES functions for substitution both between and within factors (types of labor, energy, and capital). Energy was modeled as a third factor to allow substitution among energy inputs, thus allowing sectors to adjust more realistically to environmental policies related to air emissions.

Figure 3. CES-nested Production Function



Source: Beghin and others (1996).

Consumption

Households use their income for consumption and savings. Their decision process is modeled by an extended linear expenditure system (ELES).[6] This utility function also incorporates a minimum subsistence-level consumption independent from the level of income.

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

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

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

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[6] 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.

where U represents the consumer's utility; C_i is the consumption of good i; θ is the subsistence-level consumption; S is saving; CPI is the price of savings; and μ is the marginal propensity to consume each good and to save.

Other final demands

In addition to intermediate demand and household demand, the model includes the rest of final demand: investment, government consumption, and trade margins. These demands are modeled through fixed shares of the total final demand.

Public finances

The model considers different types of taxes and transfers. The following direct taxes are defined in the model: labor tax (differentiated by occupational category), taxes on firms, and taxes on income (differentiated by quintile). The model also defines import tariffs and subsidies, as well as export taxes and subsidies (by sector). Value-added tax (VAT)—for domestic and imported goods and by sector—and specific taxes are also included.

Foreign sector

To incorporate the foreign sector, we use the Armington assumption to break down goods by place of origin, allowing imperfect substitution between domestic and imported goods and services. As with production, a CES function allows substitution between the imported and domestic baskets. Domestic supply gets a similar treatment as demand, now including a CET function to distinguish the domestic market from exports. For imports,

$$\min \quad PD \cdot XD + PM \cdot XM \text{ , subject to}$$

$$XA = \left[\alpha_d XD^{\rho} + \alpha_m XM^{\rho} \right]^{1/\rho} \quad ,$$

where PD and PM are the prices of domestic and imported goods, respectively, while XD and XM are the respective quantities. XA represents the good made up of both imports and exports, that is, the Armington good. Parameter ρ is related to the substitution elasticity between both goods.

For exports,

$$\min \quad PD \cdot XD + PE \cdot XE \text{ , subject to}$$

$$XP = \left[\gamma_d XD^{\lambda} + \gamma_e XE^{\lambda} \right]^{1/\lambda},$$

where PE is the price of the exported good and XE is the respective quantity. XP is the sector's total production. Parameter λ is related to the substitution elasticity between the domestic and exported 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 on the imposed elasticity.

Closure conditions

The model allows two alternative closure conditions for public finances. In the first, government savings are defined as fixed and equal to the original level prior to any simulation; an adjustment is allowed through some tax or government transfer to achieve government fiscal target. In the second alternative, government savings are allowed to vary, while taxes and transfers are kept fixed. The second option was chosen in the application developed in this paper.

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 final closing rule refers to balance-of-payments equilibrium. This equation is introduced into the model through Walras Law.

1.2. Environmental Specifications in the Model

The model allows three possibilities for reducing emissions of pollutants in the economy. They all introduce some kind of tax or policy that alters the economic players' decisions in their profit- or benefit-maximizing processes. The first is the most traditional and common mechanism in general equilibrium models, namely, lowering production in the most highly polluting sectors. The second involves substitution among different energy inputs that may be more or less polluting. The third possibility is to reduce emissions through the use of end-of-pipe technologies (such as filters and treatment plants). This last possibility is in the experimental stage and thus is not included in the results of our simulations.

The model does not include the possibility of technological change—stemming from investment processes based on relative returns—toward new, less polluting technologies, because this would require the use of a dynamic model. Moreover it is currently possible to change substitution elasticities to simulate more flexible technologies for less polluting processes. Also left out of the players' utility function is the environmental quality as a good for which there is a willingness to pay, which alters consumption decisions on the rest of the goods and their equilibrium prices.

Lowering production

Introducing a tax on emissions raises production costs. All things equal, this causes an increase in the price of the good produced by the polluting industry (which pays for the tax). The industry thus becomes less competitive at both the national and international levels, and the demand for the good and production both fall, at least in the long run. In the case of environmental regulation that sets a limit on emissions, the company will be forced to reduce its level of production.

These mechanisms are essentially based on making prices endogenous in the general equilibrium model, together with the possibility of reallocating factors and resources among the various production sectors (a CES function), substitution between different goods at the level of final demand (an ELES function), and substitution between the domestic and the foreign markets (a CET-Armington function).

Substitution among inputs

The use of each type of input in either production or final consumption causes a certain level of emissions independently of the production process. Therefore, another way to reduce emissions is to substitute less polluting inputs for the more polluting ones. In the case of a tax on emissions, the costs associated with using a more polluting input are indirectly increased, such that its use becomes relatively more costly and its substitution is encouraged.

In the case of a new emissions regulation, a constraint on optimization is introduced both in the domestic economy and in firms. Continuing to use the same volume of polluting inputs leads to a suboptimal situation that converges toward the original optimum to the extent that substitution occurs toward less polluting or noncontaminating inputs.

The model basically differentiates between energy-producing and non-energy-producing inputs. Non-energy-producing inputs 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 (that is, coal, petroleum-based fuels, electricity, and natural gas) are associated with the emission of up to thirteen types of pollutants (not all of which are discharged by the energy-producing inputs) through emission factors. These emission factors link the use of each money unit spent on the input to the amount of emissions of each pollutant in physical units. The total volume of emissions in the economy for each type of pollutant is therefore determined by the following equation:

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

where υ and π are the output- and input-based emissions coefficients, respectively; *XP* is total output; *XAP* is intermediate consumption; and *XAFD* other total final demands (from investment and government consumption). In other words, the total volume of emissions equals the sum of all the emissions of the pollutant, *p*, caused by all the production sectors, *i* and *j*, of the input-output matrix (seventy-four sectors for Chile) generated in their production processes per se, independently of the emissions associated with the use of polluting inputs, plus all the emissions derived from the use of both energy-producing and non-energy-producing polluting intermediate inputs: a) in the production processes of all the sectors, b) in households' consumption, h, and c) by other components of the final demand, *f*.

1.3 Further Development in the ECOGEM-model

The model can be improved in many directions to support a more complete analysis of policy options. This subsection discusses some specific improvements, including the creation of a dynamic version of the model, the inclusion of a new abatement sector in the specification, and the incorporation of a valuation of environmental quality in the utility function.

The dynamic version

Dynamics can be incorporated in the model through either a new dynamic forward-looking model or a recursive dynamic model based on the static ECOGEM-Chile model. The latter is accomplished by solving the model for several stages (periods) and linking them through the capital accumulation equation. Thus investment in period *T* becomes capital stock for period *T* + 1. Capital is then assigned among sectors according to the relative rates of return. Calibration requires a baseline scenario for the growth path, which is usually called the business-as-usual scenario. Population, labor force, depreciation, and GDP growth rates are exogenous, and the type of technical process must be chosen (the capital-labor efficiency ratio). If alternative scenarios to the base line are simulated, the technical efficiency parameter becomes constant and capital growth is determined endogenously by the saving-investment relation.

Abatement possibilities

The reduction of emissions through new end-of-pipe technologies can be incorporated in the model by introducing a new production sector that the other sectors can use to reduce their emissions. This new sector then becomes the abatement technology sector.[7] This requires a CES function that allows substitution between the abatement sector and the other sectors producing non-energy-producing intermediate inputs. The result is reflected on the following equations:

$$AB_j = \alpha_{AB\,j} \cdot \left(\frac{P_{ABND\,j}}{P_{AB\,j}} \right)^{\sigma^j_{ABND}} \cdot ABND_j \ ,$$

$$ND_j = \alpha_{ND\,j} \cdot \left(\frac{P_{ABND\,j}}{P_{ND\,j}} \right)^{\sigma^j_{ABND}} \cdot ABND_j \ , \text{ and}$$

$$P_{ABND\,j} = \left[\alpha_{AB_j} \cdot \left(P_{AB\,j} \right)^{1-\sigma^j_{ABND}} + \alpha_{ND_j} \cdot \left(P_{ND\,j} \right)^{1-\sigma^l_{ABND}} \right]^{\frac{1}{1-\sigma^j_{ABND}}} \ ,$$

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[7] Abatement technology is the current expenditure in technology to comply with an environmental regulation or to avoid paying an environmental tax.

where *AB* represents the abatement expenditure, *ND* is expenditures for the rest of non-energy-producing inputs, and *ABND* is the nest that includes both. Parameters α_{AB} and α_{ND} are the shares of each input, and σ_{ABND} is the substitution elasticity between the two inputs. P_{AB}, P_{ND}, and P_{ABND} stand for the respective prices of each input and the price of the compounded input.

Total emissions in the economy are now also determined by the existing expense in abatement. The coefficients that determine emissions are weighted by the reduction factor associated with the abatement technologies used:

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

For each sector and each pollutant,

$$\pi^* = \pi - \left(\frac{G_{\mathrm{AB}}}{\theta} \right)^{\frac{1}{\omega}} \cdot \frac{1}{\sum_i X_{ij}} \text{ and}$$

$$\upsilon^* = \upsilon \cdot \frac{\pi^*}{\pi} ,$$

where G_{AB} is the sector's expenditure in abatement technologies, X_{ij} is the intermediate demand of sector *j* for sector *i*, θ and ω are parameters from the emission cost reduction functions, and υ and π are the emission coefficients associated with the production and use of intermediate inputs, respectively.

To introduce this mechanism into the model, it is necessary to disaggregate the data for the abatement sector, calculate parameters θ and ω for each sector, and create their market. The demand is then made up of the sum of the demand of each and every sector in the input-output matrix, while the supply is determined by a new sector generated from the sectors that produce the abatement technologies, or by a proportion thereof.

Environmental quality in the utility function

Individuals value environmental quality, and they experience damage from emissions. Environmental quality should therefore be incorporated in the utility function to fully represent individuals' behavior and preferences. It allows us to endogenously assess the real costs and benefits of an environmental (or other) policy and to obtain the final welfare when agents are able to choose between traditional goods and services and environmental ones.

Although there is a large literature on the valuation of environmental damages, few CGE models incorporate environmental valuation endogenously (Perroni and Wigle, 1994, 1997; Tsigas and others, 1999), and the key parameters cannot be directly estimated. The relationship between emissions and environmental damage is usually modeled by a damage function. Current environmental quality is equal to the difference between endowments of environmental quality and damage. Thus, the individuals' valuation of environmental quality depends on the level of environmental quality and on the consumption of other goods and services. A CES utility function can model the decisions between environmental quality and the consumption nest (which, in turn, is modeled by the ELES utility function). The elasticity of substitution should be related to the income elasticity of the environmental quality valuation; the degree of responsiveness of the marginal valuation of environmental quality to an increase in damage depends on the size of the environmental quality endowments. Estimation of parameters and data on environmental quality are required in this area of development. An "environmental utility function" is not included in the CGE model presented here; consequently, our results do not consider benefits from environmental quality improvements. The cost of any environmental policy is thus overestimated. On the other hand, benefits from economic policies are also overestimated when environmental damage increases.

2. THE DATA

A very important component of any general equilibrium model is the data used. These data include information for the base year, usually an input-output matrix or a social accounting matrix, and substitution and income elasticities for each sector. Elasticities can be estimated through econometric regressions if enough information is available, or if not, other previous data can be used. The data requirements and number of parameters used make it necessary to ensure that the information is of good quality and that it is constantly updated.

2.1 Economic quality data

As in any applied general equilibrium model, the main source of information is the social accounting matrix (SAM). The matrix for

Chile was built based on the 1996 input-output matrix provided by the Central Bank of Chile (2001). The 1996 SAM is the most recent available information for Chile; it was developed by De Miguel and others (2002) based on the methodology applied by Alonso and Roland-Holst (1995) and the framework built by Venegas (1995). Data from official surveys on social variables, labor, and consumption were used, as well as foreign trade information provided by the Central Bank. This SAM has seventy-three sectors, twenty labor categories (ten rural and ten urban), ten income groups (divided by deciles), and twenty-eight trade regions.

The social accounting matrix for Chile was aggregated to enable a better mathematical convergence for the model. In the simulation exercise presented on section 3, the SAM includes eighteen economic sectors.[8] Labor is divided into skilled and unskilled, the foreign sector is not differentiated by origin, and household income is disaggregated into five quintiles. The matrix is measured in billions of 1996 pesos, although units of measure and amounts are less relevant in this type of exercise than the variables' ratio accuracy (relative weight).

Income, substitution, and other elasticities can be varied to realistically model the timing of the adjustment process. The choice of short-, medium- or long-term elasticities, as used in the relevant international literature, thus provides different degrees of flexibility according to the objective of the policy exercises. Capital accumulation processes as a function of relative returns are not included, however, as this is a static model. Intersectoral capital mobility and long-term substitution elasticities may minimize this flaw.

2.2 Emission Factors

For the Chilean case, five input-output matrix sectors are considered in the set of energy-producing inputs: oil and natural gas production, which a priori considers the extraction of petroleum and natural gas in their mining phase; coal mining; oil refining, which includes all production of heavy petroleum, gasoline, and kerosene; electricity; and gas production and distribution.

The two types of emission coefficients are input based and output related. The input-based coefficients associate emissions with the use of polluting goods that generate emissions, such as coal, gas, and oil products. The output-related coefficients tie emissions to the total

[8] The specific sectors are described in appendix A.

output of each sector. Among the thirteen types of air, water, and land pollutants with available emission coefficients, we selected those related to the air pollution problem in Santiago for the simulations. These are sulfur dioxide (SO_2), nitrogen dioxide (NO_2), volatile organic compounds (VOC), carbon monoxide (CO), and suspended particulates (specifically, particulate matter ten micrometers in diameter or smaller, or PM10).

The emission factors associated with output are obtained independently of the inputs used by each sector. We used the national SAM figures to extrapolate the data to Chile, thereby obtaining the emissions levels on the basis of the valued amount of the inputs used.[9]

2.3 Further Developments in Data

The model also includes land and water emission factors, but they have not been incorporated at this point. Further research is needed to adapt them to the local features before they can be included for Chile.

Similarly, abatement technologies cannot be included without introducing a new sector—namely, the abatement sector. It is also necessary to build cost-of-abatement curves to model the reductions stemming from the use of these end-of-pipe technologies. Both elements have been developed but not yet calibrated in the model, with the new 1996 SAM.

3. POLICY SIMULATIONS

The objective of this section is to illustrate the model's potential by analyzing a specific policy. We first perform a simple exercise of increasing fuel taxes to twice their current rate. We then highlight the model's ability to combine different policies by pairing the same fuel tax increase with a policy to reduce trade barriers.

3.1 Increased Fuel Taxes

For this exercise, we chose a restrictive tax policy that increases taxes on fuel (namely, oil refinery products) to double the current tax

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[9] 9. To examine the procedure followed to calculate emissions, together with the estimation results, see Dessus, Roland-Holst, and van der Mensbrugghe (1994).

rate (that is, a 100 percent increase).[10] We assume that the revenues obtained from this tax policy are not recycled, so government savings are increased.[11] New public savings are channeled to the market, thus increasing liquidity for investment. This policy represents an environmental policy in which contaminating fuels are taxed in order to reduce emissions. For this simulation, no capital mobility is allowed and substitution elasticities are quite flexible.[12] Sectoral adjustment will therefore tend to occur within the sector (factors/inputs) rather than between sectors.[13] Consequently, the results reflect a short- to medium-run response to the shocks.

Several impacts can be identified in this scenario. The main macroeconomic effects of increasing fuel taxes involve a decrease in basically all macroeconomic variables except investment, owing to higher fuel prices in the economy. Chile is not an oil producer, so the tax increase has important effects on production (–1 percent), consumption (–1 percent), imports (–1.5 percent), and exports (–1.6 percent). This causes a fall in real GDP of 0.5 percent. Capital immobility triggers a rougher adjustment because it impedes intersectoral reallocations, and a restricted equilibrium is achieved where macroeconomic effects are enhanced. However, the growth of investment (0.5 percent) owing to the boost in government savings reduces the overall impact by half. Real government savings increase by over 11.4 percent, from roughly 2.5 to 2.75 percent of GDP. Corporate savings, however, fall by 0.9 percent.

Sectoral impacts are perhaps the most significant in the model. Table 1 shows the impacts on sectoral output, employment, exports, and imports. The sectors that are negatively affected are those involved in the extraction or refinery of oil products, as well as the transport-related sectors, which directly depend on oil. The substitutes electricity and coal are now relatively cheaper, and their output thus increases. The construction sector also benefits from the policy

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[10] The results presented in this section do not pretend to be real and useful for policy application, but rather are intended to show the possibilities of the model. Real applications require a deep analysis.

[11] Other options are also possible. For example, the revenue can be used to offset another inefficient tax, which is modeled in section 3.2.

[12] The elasticities used in the present simulation are similar to those assumed by other studies for Chile (Coeymans and Larraín, 1994; Beghin and others, 2002; Harrison, Rutherford, and Tarr, in this volume). In another paper, we undertake a sensitivity analysis in which we use the same model to show differences in the model when assuming other elasticities (O'Ryan, Miller, and De Miguel, 2003).

[13] Appendix B presents the same simulation assuming full capital mobility across sectors.

Table 1. Sectoral Effects
Percent

Sector	*Production*	*Labor*	*Exports*	*Imports*
Renewables	–1.0	–0.3	–2.5	0.4
Nonrenewables	–0.8	–0.5	–1.0	–0.4
Oil and gas extraction	–11.5	–14.0	–14.3	–29.2
Coal	2.1	3.7	–3.0	5.3
Food industry	–0.6	–0.2	–1.0	–0.2
Textiles	0.0	0.3	0.0	–0.1
Wood products	–0.9	–0.7	–1.4	–0.2
Chemicals	–0.5	0.0	–0.8	–0.3
Oil refinery	–26.8	–31.8	–67.4	6.3
Manufactures	–0.1	0.3	–0.3	0.0
Electricity	0.6	3.2	–	3.6
Gas	–1.2	1.6	–	–
Hydraulic	–0.1	0.3	0.5	–0.3
Construction	0.4	1.2	–	0.8
Commerce	–0.5	–0.3	–0.6	–0.4
Road transport	–3.6	0.1	–15.7	0.9
Other transport	–3.5	–2.8	–4.8	–1.3
Services	–0.1	0.2	0.7	–0.3

Source: Authors' calculations.

as a result of the higher level of investment, which has its origin in the increased public savings. Employment (labor demand) by sector follows the same path as production, increasing when output grows and decreasing otherwise.

The remaining sectors, which are mainly primary and industrial, experience minor negative effects on their output, which leads to an overall reduction in the economy's production. The main reason is the increase in production costs owing to higher energy costs. This also causes a decrease in wages, as some jobs are cut. This reduces the household income, as shown below.

Imports and exports also vary by sector. The greatest impacts correspond to the sectors that were most strongly affected by the policy, as expected. Most sectors reduce both their imports and exports, although some imports are increased as a result of lower production costs elsewhere. The overall effect is a reduction in trade activity, with a decrease in both total imports and total exports.

All households are negatively affected. In terms of income and prices, the effect is roughly the same for all income groups (see table 2). Real income falls almost 1 percent. The effects on welfare may vary, however. If the utility level is used to measure the welfare effects, the poorest groups are more negatively affected than groups with a higher income. This is due to the definition of the utility function, which

Table 2. Impacts on Households and Welfare
Percent

	Househould income quintile				
Variable	*First*	*Second*	*Third*	*Fourth*	*Fifth*
Real income	–1.0	–1.0	–1.0	–1.0	–0.9
Income	–0.6	–0.6	–0.6	–0.6	–0.6
Prices	0.4	0.4	0.4	0.4	0.4
Utility	–1.0	–1.0	–0.9	–0.8	–0.4

Source: Authors' calculations.

considers a decreasing marginal utility. Furthermore, the tax increase has a direct impact on the minimum subsistence consumption (heating, transportation, and so forth), and this represents a greater share of poorer consumption baskets.

Finally, the model identifies the environmental effects of increasing fuel taxes. The basic effect on emissions is clearly positive, since the emission levels of all pollutants are reduced. One of the main pollution problems in Chile is PM10 emissions in Santiago. With this policy, they are reduced by 15.8 percent. SO_2 and NO_2 emissions are also reduced significantly, by 17.3 percent and 17 percent, respectively. Smaller reductions are observed for carbon monoxide (5.9) and volatile organic compounds (2.9).

3.2 Increased Fuel Taxes and a Tariff Reduction

The model allows the combination of different policies. The simulation presented in this subsection combines an environmental policy linked to fuel taxation and a policy that reduces trade barriers. We thus use the same increase in fuel taxes modeled above, but this time the government applies a tax substitution in which the revenues are channeled to finance tariff reductions. Government savings remains constant at the initial level.[14] The exercise incorporates the same technical characteristics and assumptions as the previous simulation.

The macroeconomic variables are less affected by the rise in fuel taxation than in the previous simulation. The decrease in tariffs partially compensates the recessive effect of the environmental taxation by encouraging trade and reducing the prices of imported goods and

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[14] Different fiscal policies can be simulated when the government wants to maintain public revenues in the face of tariff reductions linked to free trade policies. Here, we use the fuel tax, but VAT, specific taxation, income taxation, transfers/subsidies, and so forth can also be explored and compared.

services for production and consumption. These variables still fall, but the impact is smaller with the trade policy: production (–0.9 percent, versus –1 percent in the last simulation), consumption (–0.6 percent versus –1 percent), imports (–0.6 percent versus –1.5 percent), and exports (–0.7 percent versus –1.6 percent). Consequently, the effect on real GDP is also smaller, at –0.4 percent (versus –0.5 percent above). Public savings remain constant, since revenues from fuel taxation are used to compensate shrinking revenues from tariffs. Aggregate corporate savings experience a small impact (–0.2 percent), although strong differences are seen at a sectoral level depending on trade orientation and the intensity of fuel use. Because aggregate savings remain almost constant, investment also essentially remains constant (0.1 percent). Tariff revenues drop by roughly 14.5 percent.

At the sectoral level, most sectors improve their situation relative to the previous simulation (see table 3). In fact, most of the negative results involve exports, whereas imports and employment now experience a positive impact. Production also benefits from the tariff reductions. Local energy production (oil and gas extraction and coal) is reduced further since these substitutes are bought in from abroad in response to the lower tariffs, and construction is not affected since investment does not increase.

Table 3. Sectoral Effects
Percent

Sector	*Production*	*Labor*	*Exports*	*Imports*
Renewables	–0.7	0.0	–1.6	2.3
Nonrenewables	–0.5	0.1	–0.5	1.2
Oil and gas extraction	–11.7	–14.6	–12.2	–28.1
Coal	1.5	2.6	–1.2	7.3
Food industry	–0.3	0.1	0.0	2.0
Textiles	0.1	0.4	1.8	1.3
Wood products	–0.6	–0.3	–0.5	1.7
Chemicals	–0.4	–0.2	1.0	0.9
Oil refinery	–26.0	–31.6	–65.7	10.1
Manufactures	–0.1	0.0	2.3	0.5
Electricity	0.7	2.9	–	3.1
Gas	–0.7	1.6	–	–
Hydraulic	0.0	0.3	1.5	–0.4
Construction	0.1	0.5	–	–0.3
Commerce	–0.4	–0.2	0.5	–0.7
Road transport	–3.2	0.2	–13.5	0.7
Other transport	–2.7	–1.8	–3.6	–1.0
Services	0.0	0.2	1.4	–0.5

Source: Authors' calculations.

Table 4. Impacts on Households and Welfare
Percent

	Househould income quintile				
Variable	*First*	*Second*	*Third*	*Fourth*	*Fifth*
Real income	–0.7	–0.6	–0.6	–0.6	–0.6
Income	–0.6	–0.6	–0.6	–0.6	–0.6
Prices	0.1	0.0	0.1	0.1	0.0
Utility	–0.7	–0.6	–0.6	–0.5	–0.3

Source: Authors' calculations.

Table 4 shows the negative impact on all households. The price effect is now smaller, however, so both utility and real income improve relative to our previous simulation. The regressive effect remains.

The positive environmental effects decrease slightly for all emissions. PM10 emissions are reduced by 14.5 percent (versus 15.8 percent in the simulation without the trade policy), SO_2 by 16 percent (versus 17.3 percent), NO_2 by 15.7 percent (versus 17 percent), carbon monoxide by 4.4 percent (versus 5.9 percent), and volatile organic compounds by 2.5 percent (versus 2.9 percent).

In summary, the simulated combination of environmental and trade policies seems to have more benefits than the environmental policy alone: the environmental effects are still strong, but the macroeconomic and social impacts are smoother. At a sectoral level, the degree of the impact depends on the intensity of fuel use and relations with foreign markets.

4. CONCLUSIONS

This paper presents an empirical application of the computable general equilibrium ECOGEM-Chile model using the latest available economic information for Chile (1996). The model is very flexible and comprehensive, and it permits an analysis of the impact of policies and external shocks on different economic agents. It includes detailed disaggregations by sector (seventy-two sectors), labor (twenty categories), trade partner (twenty-seven countries), and household (ten income groups). It incorporates energy-input substitution possibilities and input-based emissions of up to thirteen different pollutants. It can analyze the effects on macroeconomic, sectoral, social, and environmental variables. ECOGEM-Chile is thus a useful tool for analyzing policies and external shocks that may affect the most important economic agents in Chile.

To illustrate some of the model's features, we simulated the impact of a 100 percent increase in fuel taxes. The results of this simulation show negative impacts on aggregate variables such as consumption, production, trade, and GDP. We assumed that government expenditure does not vary, so public savings increase. This generates a rise in investment, which partially offsets the fall in GDP. An analysis of the sectoral impacts pointed to winning and losing sectors. The winners from the policy are those sectors that provide alternative energy products, such as electricity (mainly hydropower) and coal. Construction also benefits as a result of the higher levels of investment. The losing sectors identified are oil extraction and production and the transport sector. Other sectors are also affected, mainly negatively, but to a lesser degree.

Households are also negatively affected by the policy, partly through an increase in domestic prices and partly through a decrease in income. The latter results from sectors laying off workers, which reduces the average wage. All households are affected at the same rate. Finally, we observe the positive impacts related to an important emission reduction for all pollutants, which reaches 17 percent in the case of SO_2 and NO_2 and 15 percent in the case of PM10 emissions. The environmental benefits were not valued, and thus the impact on economic welfare is uncertain.

We also simulated a mix of environmental and trade policies to show the benefits from policy coordination and to discuss alternative closure rules. Here, real public savings remain constant, and all revenues from fuel taxation are compensated by equivalent reductions in trade tariffs. Sectors now suffer from two shocks: an increase in fuel taxes and a reduction in tariffs. The results show that most impacts on macroeconomic, social, and environmental variables are smoothed, thereby achieving better average results. These results depend, however, on each sector's energy pattern and trade orientation.

No capital mobility was allowed in either of the simulations presented, and the results thus represent a short- to medium-term adjustment. Sectoral impacts would increase with capital mobility, as capital flows from less to more profitable sectors. Additionally, the model has ample flexibility for simulating reductions in other taxes (such as VAT or corporate taxes), as well as a reallocation of the increased public revenues to subsidies, transfers, or public expenditure.

The main aim of this paper is to show the potential of general equilibrium analysis. Consequently, the results should not be seen as conclusive for future fuel tax or trade policies. The model results should be considered as only part of any policy analysis, which generally also requires an in-depth examination of the results obtained by sectoral specialists. Several improvements could enhance the model's capabilities for environmental analysis—in particular, the development of a dynamic version, the inclusion of an "environmental utility function," and the simulation of policy exercises applying the equations related to abatement technologies presented in this paper. Similarly, natural gas needs to be integrated as an important energy input in the Chilean economy; it is only partially included in the 1996 input-output matrix because natural gas became available in significant volumes only in 1997. Despite these limitations, the present core model considers most of the economic features of the CGE literature, it has a huge level of economic detail and data desegregation, and it includes useful environmental and energy characteristics.

Finally, the results show that the model is highly effective for systematically and holistically analyzing different policies and their impact on Chile's economy. The model can evaluate external price shocks, trade policies, tax reforms, social and environmental policies, and other policies, together with their separate impacts on different income groups and production sectors and their aggregate impacts.

APPENDIX A

Sectors Used

Aggregate sector	*1996 input-output matrix code*	*Description*
Renewables	1–5	Agriculture, fruit, livestock, forestry, fisheries
Nonrenewables	8–10	Copper, iron, other minerals
Oil and gas extraction	7	Oil and gas extraction
Coal	6	Coal
Food industry	11–25	Meat, dairy, preserves, seafood, oils, bakery, milled products, sugar, other foods, animal feed, beverages, wine, liquor, beer, tobacco
Textiles	26–29	Textile, clothes, leather, shoes
Wood products	30, 31, 46	Wood products, furniture, pulp and paper
Chemicals	32, 34–38	Printing, chemicals, other chemicals, rubber, plastics, glass
Oil refinery	33	Oil refinery
Manufactures	39–45,47	Nonmetallic minerals, iron and steel, nonferrous metals, metal mechanics, nonelectric machinery, electric machinery, transport materials, other manufactures
Electricity	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	61–74	Communications, banking, insurance, leasing, services to firms, real estate, public education, private education, public health, private health, entertainment, other entertainment, other services, public administration

Source: Authors' elaboration and Central Bank of Chile (2001).

APPENDIX B

Comparison of Impacts with and without Capital Mobility

Table B1 compares the results of a specification assuming full capital mobility across sectors with one featuring zero capital mobility. As the table indicates, the impact on sectoral output is much higher under full capital mobility than under zero capital mobility. This is due to the possibility of installing and uninstalling capital, which allows the sectors to adjust their production at a lower cost. This has a negative impact on households, however: since the winning sectors no longer require a high amount of additional labor, the average wage falls slightly.

From a macroeconomic perspective, full capital mobility generates a slightly higher impact on GDP, consumption, and investment and a relatively lower impact on production and trade. The latter arises from the possibility of switching capital from one sector to another, leading to increased output in winning sectors. Finally, the environmental impacts are also slightly higher, owing to the growth of a cleaner energy sector.

Table B1. The Effect of Capital Mobility across Sectors

Percent

Variable	*No capital mobility*	*Full capital mobility*
Macroeconomic		
Production	–1.00	–0.80
Consumption	–1.00	–1.20
Investment	0.50	0.80
Exports	–1.60	–1.50
Imports	–1.50	–1.20
Real GDP	–0.50	–0.60
Absorption	–0.50	–0.50
Real government savings	11.40	14.20
Corporate savings	–0.90	–1.10
Sectoral production		
Renewables	–1.00	–1.80
Nonrenewables	–0.80	3.30
Oil and gas extraction	–11.50	–14.50
Coal	2.10	11.10
Food industry	–0.60	–0.80
Textiles	0.00	0.70
Wood products	–0.90	–2.10
Chemicals	–0.50	0.00
Oil refinery	–26.80	–32.60
Manufactures	–0.10	1.10
Electricity	0.60	10.10
Gas	–1.20	0.30
Hydraulic	–0.10	0.70
Construction	0.40	0.70
Commerce	–0.50	–0.50
Road transport	–3.60	–5.30
Other transport	–3.50	–13.60
Services	–0.10	0.40
Real income		
First quintile	–1.00	–1.30
Second quintile	–1.00	–1.30
Third quintile	–1.00	–1.30
Fourth quintile	–1.00	–1.20
Fifth quintile	–0.90	–1.10
Environment		
SO_2	–17.30	–19.90
NO_2	–17.00	–19.60
CO	–5.90	–3.80
VOC	–2.90	–3.00
PM10	–15.80	–17.90

Source: Authors' calculations.

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