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Trade integration, environmental degradation, and public health in Chile: assessing the linkages

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ABSTRACT. We use an empirical simulation model to examine links between trade integration, pollution, and public health in Chile. We synthesize economic, engineering, and health data to elucidate this complex relationship and support more coherent policy. Trade integration scenarios examined include Chile's accession to the NAFTA, MERCOSUR, and unilateral opening to world markets. The latter scenario induces substantial worsening of pollution, partly because it facilitates access to cheaper and dirty energy, and has a significant negative effect on urban morbidity and mortality. Damages caused by rising morbidity and mortality are of similar magnitude and substantial. Emissions of small particulates, SO_2, and NO_2, have the strongest impact on local mortality and morbidity. These three pollutants appear to be complementary in economic activity. Unilateral trade integration combined with a tax on small particulates brings welfare gains, which are 16 per cent higher than those obtained under unilateral trade reform alone.

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Introduction

The policy significance of trade and environment linkages has increased sharply in recent years, largely because of a higher profile in trade negotiations such as the Uruguay Round and the NAFTA. Among academic observers, the consensus view is that trade policy is not an adequate tool for environmental protection (Beghin, Roland-Holst, and van der Mensbrugghe, 1994), but many other aspects of this linkage remain contentious issues and will remain central to the policy debate (Whalley, 1960).

Unfortunately, the empirical evidence to inform this debate is still scarce, and this scarcity motivates the present paper. In particular, we seek to quantify the direct and indirect effects of environmental taxes, including their output and trade effects, as well as their interaction with trade policies and their incidence upon the environment, public health, and welfare. For fast-growing developing economies, greater outward-orientation holds promise in terms of growth and efficiency. Pursuing this goal blindly, however, may jeopardize long-term prosperity because of the environmental costs of such a strategy. Hence, it is essential to assess the environmental impact of trade policy generally and trade liberalization in particular, and to examine how these might be better co-ordinated with environmental policies to mitigate environmental degradation.

Our paper makes several contributions. Firstly, we explicitly incorporate links from trade to environment to public health indicators, rather than simply measuring pollution incidence or other environmental variables. Secondly, this paper is empirical, and intended to strengthen the basis of evidence for the rapidly evolving policy debate on trade–environment linkages.[2] The present paper gives empirical evidence for Chile, but the methodology can be extended to other countries. Using an applied general equilibrium model, we investigate the interactions between trade and environmental policies, focusing particularly on trade liberalization and co-ordinated policies of effluent taxation. We provide estimates of emissions for detailed pollution types at the national level, and for the Santiago Metropolitan Area, identifying patterns of pollution intensity that emerge with greater outward orientation. We then make more tangible the linkages between economic valuation, emissions, ambient pollution and public health indicators in Santiago, building upon recent work on urban pollution and public health indicators in Santiago (World Bank, 1994; Ostro *et al.*, 1995; O'Ryan, 1993; and Comision National del Medio Ambiente, 1998). In particular, we quantify the incremental mortality and morbidity associated with combined economic and environmental polices and their

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[2] The recent empirical literature on trade and environment linkages has looked at the interaction between environmental regulation in the North, foreign investment and firms on the international division of labor and the emergence of pollution havens (Eskeland and Harrison, 1997; Low and Yeats, 1992), and the interaction between openness and specialization, and associated pollution intensity of output and trade (Beghin, Roland-Holst, and van der Mensbrugghe, 1995; Birdsall and Wheeler, 1992; Grossman and Krueger, 1992; Hettige, Lucas, and Wheeler, 1992; Lee and Roland Holst, 1997; and Ferrantino and Linkins, 1999).

monetary damages. Because its topology, local climate, and economic concentration make this urban area comparable to Mexico City and Jakarta, pollution in Santiago poses a major environmental challenge to Chilean policy makers, well into this century.[3]

In this context, we find that abatement of three air pollutants (small particulates, SO_2, and NO_2, a determinant of ozone) has the largest impact on mortality and morbidity and far outweighs the health benefits which might arise from abatement of other air pollutants in Santiago. We also find that Chile's accession to the NAFTA, compared to unilateral trade liberalization, would reduce the emissions of many pollutants and have a relatively benign effect on urban public health. Unilateral integration, by contrast, would appear to induce a significant transfer of pollution capacity to Chile from the Rest of the World, adversely affecting the environment and public health. Here the case for co-ordination with environmental policy is compelling indeed.

Until 1975, Chile followed an import-substitution strategy and was replete with trade distortions, foreign exchange restrictions and resulting misallocation of resources. Following a series of policy reforms under the structural adjustment of the 1980s, Chile eventually emerged as a thriving outward-oriented economy since the mid 1980s (Papageorgiou, Choksi, and Michaely, 1990; World Bank, 1994).[4] This continued economic expansion has fostered rising living standards and also concerns for the environmental consequences of the growth, especially in the Santiago Metropolitan Area (World Bank, 1994). In parallel, urbanization is already well advanced in Chile, where about 85 per cent of the population live in or within the vicinity of major cities (for example, Santiago Metropolitan Area and Valparaiso). The income growth and rapid urbanization have outpaced the development of infrastructures, such as paved roads, public transportation equipment, and sewage treatment systems. Several environmental problems in urban areas are linked to the poor road infrastructure and the use of untreated wastewater used in irrigated agriculture (World Bank, 1994).

The infrastructure problem exacerbates air pollution in Santiago by contributing to emissions of suspended particulates and other effluents in the air. This problem combined with unique topological and climatic conditions (thermal inversion) put Santiago in the league of the most-polluted cities in the world. Rising incomes and health concerns are at odds with this situation. With the assistance of international organizations, Chile has

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[3] For example, total suspended particulates (TSP) and respirable particulates (PM-10), ozone and CO concentrations in Santiago are in excess of established standards for several months every year (World Bank). The one-year average concentration of PM-10 was estimated at $108.7\mu g/m^3$, in Santiago in 1992 and $87.85\mu g/m^3$ in 1997.

[4] According to Penn World Tables, real income per capita grew 1.68 per cent annually from 1950 to 1973. In the decade following the crisis of 1973–1975 the average real income per capita grew erratically at the average rate of 1.53 per cent per year. Since 1985 real income per capita has been growing at 5.02 per cent a year. According to the IMF's International Financial Statistics, real GDP grew at the annual rate of 7.68 per cent during the 1990s.

started addressing these environmental problems, especially, air and water pollution in Santiago, but environmental regulation remains limited (Birdsall and Wheeler, 1992; World Bank, 1994).

A critical mass of information has recently been accumulated on urban pollution in Santiago (O'Ryan, 1993; Sanchez, 1992; Turner, Weaver, and Reale, 1993; World Bank, 1994; and Dessus and O'connor, 1999). We make use of this information when we link national pollution estimates to pollution concentrations in Santiago. Our study is a useful contribution to the existing work on Santiago for several reasons. It provides estimates of pollution emissions at the national level and of their variations induced by policy changes and links them to ambient pollution in Santiago. Second, our valuation of the change in mortality in Santiago resulting from policy reforms is based on a willingness-to-pay approach (Bowland, 1997; Dessus and O'connor, 1999), which is more accurate than the World Bank's human capital approach (World Bank, 1994). The latter merely serves as a lower bound on the value of a life saved, but it is not terribly informative.

The TEQUILA Model

The *Trade and Environment eQUILibrium Analysis* (TEQUILA) model is a prototype computable general equilibrium model developed at the OECD Development Centre for research on sustainable development.[5] The full model documentation is available on the Internet and described in Beghin *et al.* (1996). TEQUILA is novel in its environmental components, especially in this Chilean application which encompasses emissions, dispersion, and the health impact of pollution. We devote most of this section to the latter features, since the remaining structure of the model is well established in CGE modelling.

The model is multi-sectoral (72 sectors for Chile) with careful disaggregation of pollution-intensive and natural-resource-based sectors and their linkages to manufacturing. Natural resource activities include five mining and extraction sectors and seven other sectors. Four wood-based sectors, four oil-based chemical industries, and eight mineral-based activities capture the linkages between natural resources and pollution-intensive manufacturing.

Output is characterized by CRS technology and the structure of production consists of a series of nested CES functions taking into account optimizing behaviour in the choice of production factors. Output results from two composite goods: non-energy intermediates and energy plus value added. The intermediate aggregate is obtained by combining all products in fixed proportions (Leontief structure). The value added (VA) and energy component is decomposed in two parts: aggregate labour and capital and energy (KE). The capital–energy bundle is further disaggre-

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[5] The Chilean investigation is part of the research program of the OECD Development Centre on the interface between growth, trade and the environment, with a focus on Pacific countries: Chile, China, Costa Rica, Indonesia, Mexico, and Vietnam (see Beghin, Roland-Holst, and van der Mensbrugghe, 2002; Lee and Roland-Holst, 1997; and Dessus and Bussolo, 1998 for companion papers).

gated into its basic components. By using a putty/semi-putty specification, the model distinguishes between the allocation of capital existing at the beginning of the period, or already installed (old capital), and that resulting from current investment (new capital), assigning different substitution elasticities to each. Finally, the energy aggregate includes four types of energy that are substitutes: coal, oil, natural gas, and electricity.

Substitution elasticities reflect adjustment possibilities in the demand for production factors originating from variations in their relative price. In particular, the central elasticity values in the model are: 0.00 between intermediates and value added with old capital plus energy; 0.50 between intermediates and the VA/KE aggregate incorporating new capital plus energy; 0.12 between aggregate labour and the old capital-energy bundle; 1.00 between aggregate labour and the new capital–energy bundle; 0.00 between old capital and energy; 0.80 between new capital and energy; 0.25 among different sources of energy associated with old capital; 2.00 among those associated with new capital. These values reflect conventional wisdom on plausible parameter values for developing economies (see Sadoulet and de Janvry, 1995, chapter 12). These conservative values are less likely to overstate abatement possibilities through substitution away from dirty inputs (the so-called technique effect) and make the model building transparent. Higher elasticity values would induce larger abatement via the technique effect and would decrease abatement through composition (cleaner sectoral composition of GDP and consumption) and scale (aggregate output contraction) when pollution is taxed.[6]

Most economywide models investigating pollution issues assume fixed proportion between sectoral output and emissions (see, for example, Lee and Roland-Holst, 1997; and Espinosa and Smith, 1995). By contrast, we posit substitution possibilities between value added, energy, and non-energy intermediate goods, which allow the decrease of pollution associated with production if pollution taxes are put in place. This is a major improvement in the incorporation of pollution in economywide modelling. We econometrically estimate the pollution effluents by sector as being a function of energy and input use (Dessus *et al.*). Estimates of these input-based effluents intensities are obtained by matching data from a social accounting matrix disaggregated at the 4-digit ISIC level to the corresponding IPPS pollution database of The World Bank (Martin *et al.*, 1991). Both the final consumption and the intermediate use of polluting goods generate emissions. Excise/effluent taxes are used to achieve pollution abatement. These taxes are measured as unit of currency per unit of emissions and are uniform taxes *per unit of effluent* for all sectors. Since every sector has different effluent intensities, the pollution tax, expressed *per unit of output*, varies across sectors.

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[6] Our decomposition of pollution follows Copeland and Taylor (1994) and Beghin, Roland-Holst, and van der Mensbrugghe (1997), which differs from Grossman and Krueger's (1992). The major difference resides in the technique effect. Grossman and Krueger include technical change in their technique effect; by contrast we consider movements along an iso-production surface away from polluting inputs with given technology.

A vector of 13 measures of effluents characterizes pollution by sector. Pollution intensity varies by sector and with relative prices, since the use of 'dirty' inputs is influenced by relative price changes induced by policy intervention. The measures include: toxic pollutants released in water, air, and land (TOXAIR, TOXWAT, TOXSOL); bio-accumulative toxic metals, including lead in air, soil, and water (BIOAIR, BIOWAT, BIOSOL); air pollutants, such as SO_2, NO_2, COx, volatile organic compounds (VOC), and particulate intensity (PART); and, finally, water pollution measured by biological oxygen demand (BOD) and total suspended solids (TSS). For the computation of the health impact in Santiago we consider air pollution emissions for PART inclusive of small particulates (PM-10), lead, SO_2, NO_2, COx, and VOC.

We pay extra care to two major air pollutants, which bear significantly on our results, PM-10 and lead. For PM-10, recent ambient concentration data for Santiago indicate significant reductions since the early 1990s.[7] We therefore assume that policy will have a significant impact on particulate emissions over the scenario period, in particular, that the sectoral emission coefficients will decline at a rate of 3 per cent per annum to 2010. For lead, we apply the regulation on lead content of gasoline in Santiago of 0.18 g/l effective from 1995 to base-year gasoline consumption to estimate motor vehicle-related lead emissions. Then we allocate the lead emissions not accounted for by gasoline in the base year to other sectors in accordance with the US coefficients, constraining total Santiago emissions to yield the average ambient concentration of 1.5 mg/m given the dispersion function. Chile intends to phase down leaded gasoline use over time and we incorporate a 75 per cent reduction in the transport sector emission coefficient for lead over the period to 2010. Despite these assumptions, lead emissions grow significantly in the baseline. This is caused by the high-income elasticity of demand for transport services, and also by the growth of lead-emitting industrial sectors. The non-transport-sector emission coefficients are kept constant at their base-year values, since we do not make conjectures on policy initiatives relating to lead sources other than gasoline combustion.

Some dynamic components in TEQUILA also influence emissions. The first is factor accumulation. Labour supply is assumed to grow exogenously, while the capital stock evolves with investment activity. The second element is productivity growth. There are efficiency factors for capital, labour (by each occupation), and energy. The efficiency factors are normally exogenous, but the capital efficiency factor is imputed in the benchmark simulation to achieve a specified trajectory of real GDP growth. These assumptions mean that a same dollar of output emits less pollution over time. The third element is a vintage capital assumption. The composition of the capital stock, which will determine the degree of flexibility in production, will be influenced by the time path of total and sectoral investment allocation.

The model assumes imperfect substitution among goods originating from different geographical areas. Import demand results from a CES

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[7] We thank a referee for providing some of the data on these concentrations.

aggregation function of domestic and imported goods. Export supply is symmetrically modelled as a Constant Elasticity of Transformation (CET) function. Producers decide to allocate their output to domestic or foreign markets responding to relative prices. Elasticities between domestic and foreign products are of comparable magnitude for import demand and export supply. Their values are 3.00 for agricultural goods, 2.00 for manufactured goods and 1.50 for services. The small country assumption holds, thus imports and exports prices faced by Chile are exogenous, with two exceptions. We assume that copper and fishmeal exporters face a finite demand with an own-price elasticity of –5. The balance of payments equilibrium determines the final value for the current account. Finally, trade distortions are expressed as *ad valorem* tariffs. The latter assumption reflects the tariffication of most trade distortions in Chile following its structural reforms. We calibrate the TEQUILA model using a detailed social accounting matrix of Chile for 1992, which is then updated for 1997 using actual income data. The pollution inventory refers to 1997.

The Santiago health module[8]

This section outlines how we map predicted pollution emissions from our simulations into health effects for residents of Santiago, and then ascribe monetary damages to the health impacts of pollution. The model estimates the change in health status associated with a change in major air pollutants by each of 72 industrial activities in Santiago. Changes in industry emissions are obtained from the economywide model. The health effects module transforms these emissions data into corresponding changes in health status (for example, reduction in PM-10 related mortality). In so doing, the health-effects component is used to estimate the potential health damage savings (costs) corresponding to alternative trade and environment policy scenarios analysed by the economywide model.

In characterizing emissions, we use the most recent (1997) baseline information on major air pollutants and emission sources for Santiago (Comision Nacional Del Medio Ambiente). We collect and combine data on pollutants causing significant health problems in Santiago, the corresponding emission sources, and baseline average annual emissions and ambient concentration levels. The data are used to estimate the portion of economywide emissions attributable to Santiago in 1997, as well as calibrate the health module of the CGE model to initial conditions.

Dispersion modelling maps effluent emissions into ambient concentration levels, and population-weighted concentration levels are used to determine exposure rates for health impacts. The next step involves calculating the health status response to changes in concentrations of air pollutants. Dose response functions express the change in incidence of mortality/morbidity induced by changes in pollution concentrations (Ostro *et al.*, 1995). The figures on health end-points presented in the results section should be interpreted as increases or decreases in mortality

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[8] A detailed appendix is provided upon request.

Table 1. *Unit valuation of incidence of morbidity in the US and Chile: value of statistical life for mortality valuation in Chile*

	*Measure**	*US unit values** (1992 PPP$)*	*Chilean unit values*** (1992 PPP$)*
Respiratory hospital admission (RHA)	COI	7,058	5,871
Emergency room visit (ERV)	COI	199	166
Restricted activity day (RAD)	COI	57.70	47.8
Bronchitis in children (LRI)	COI		160
Asthma attack-day	CV	33.94	5.77
Any symptom-day (respiratory related)	CV	6.79	1.15
Chronic bronchitis in adults	CV	237,604.84	197,633
Minor respiratory restricted activity day (MRRAD)	CV	24.30	20.2
Cough day (or child respiratory symptom day)	CV	5.40	4.5
Chest discomfort case	CV	6.79	5.6
Respiratory symptom day (or pleghm day)	CV	6.79	5.6
Eye irritation	CV	6.75	5.6
Headache episode (average of mild and severe)	CV	27.19	22.6
IQ decrement (per 1 point IQ loss)	COI	2957	2460
Hypertension case	Medical costs only	696	579
Non-fatal heart attack	Medical costs only	53,040	44,117
Value of statistical life (mortality valuation under BAU)***	CV, HWM	2,500,000	2,100,000

Notes: * Type of study used to derive health valuation measure: cost of illness (COI), contingent valuation (CV), hedonic wage model (HWM), or medical costs only (value of lost wages not included).

** Central unit values taken from US studies by ORNL and RFF Desvousges *et al.*, and Dessus and O'Connnor (1999). Values from these studies adjusted to 1992 US$ based on CPI (base 1987 = 100). Note: conversion of US$ to PPP$ not necessary since PPP$ are derived relative to the U.S.$ (i.e., US$1 = $1 PPP).

*** Estimated using the *relative incomes approach* {US unit value * [(Chilean GDP/capita 2010 in 1992 PPP$)/(US GDP/capital 1992 in 1992 PPP$)]^e}. Estimate reflects relative income measure of 0.86 based on ratio of Chilean GDP/capita in 2010 to US GDP/capita in 2010, both in 1992 PPP$ terms. The conversion assumes an income elasticity for health effect of $e = 1$.

and morbidity with respect to the BAU mortality and morbidity. We look at the following indicators: premature mortality due to PM-10, SO_2, and ozone; premature mortality in males of age 40–59 due to lead; respiratory hospital admissions (for PM-10, ozone); emergency room visit (for PM-10); restricted activity days (for PM-10); lower respiratory illness for children population of age less than 17 (PM-10); asthma symptoms for asthmatic population (for PM-10, ozone); respiratory symptoms (for PM-10, ozone); chronic bronchitis in population of age 25 or older (for PM-10); minor restricted activity days (for ozone); respiratory symptoms in children population (for SO_2); chest discomfort in adult population (for SO_2); respiratory symptoms in adult population (for NO2); eye irritation in adult population (for ozone); number of headaches in adult population (for COX); IQ decrement in children population (for lead); cases of hypertension in adult male population (for lead); and non-fatal heart attacks in male population age 40–59 (for lead).

Finally, we attach a monetary value to the health impact figures (see table 1). We follow a willingness-to-pay approach to valuing morbidity and loss of life due to a change in mortality, relying on the large body of information and data on such measures for industrialized economies to econometrically estimate these damages for Chile. Damages due to mortality are based on the value of a statistical life. The latter indicates the aggregate valuation by individuals of reducing the risk of dying. For Santiago, our estimate is roughly 2.1 million dollars per life, in 1992 (purchasing power parity) US dollars. This estimate corresponds to the value of a life reached in 2010 evaluated at risk and income levels of the business-as-usual scenario (Dessus and O'Connor, 1999).

Because of the scarcity of morbidity estimates available for industrialized countries, our willingness-to-pay measures are less sophisticated for morbidity. Available estimates from industrialized countries were simply scaled down to reflect the per capita income differences between Chile and these industrialized countries in 2010, expressed in (PPP) 1992 US dollars. Finally, we assume that commodity and environmental consumptions are separable and that welfare consequences of reforms are the sum of the welfare effects in commodity markets and environmental health damages.

Policy reform scenarios

The time horizon of the simulations is the period 1997–2010. We first define a reference trajectory for the economy based on DRI-McGraw-Hill predictions of GDP growth until 2010. Factor and energy productivity changes are endogenously determined such that the GDP forecast and the model are consistent with each other. Trade and environmental policies are held constant in this reference scenario, called the business-as-usual (BAU) scenario. For the years 1997–2010, the model gives us the reference trajectory base for output, absorption, trade, and pollution emissions, for this BAU scenario. This is the base or reference trajectory of the economy for our analysis. All reported results for the reform scenarios are expressed in deviations (in per cent) from this BAU scenario and for 2010, the final year of the simulation exercise.

The first reform scenario imposes taxes on pollutants, one at a time.[9] Each tax level is endogenous and is such that the emissions of the targeted pollutant progressively decrease over time and reach a 25 per cent decrease relative to its level in the BAU results by 2010. The phasing in of these taxes is set to obtain gradual reductions of 15 per cent in 2000, 20 per cent in 2005, and 25 per cent in 2010. The tax rates per unit of effluent are the shadow prices of the quantitative constraints on the pollution emissions.

The second scenario considers gradual trade integration, combining unilateral trade liberalization through tariff reduction *vis-à-vis* all trade partners, with a concurrent but modest improvement of terms of trade. Terms of trade are parametric for Chile, assumed to be a small country, and the terms-of-trade improvement is introduced as an exogenous shock to mimic transaction cost reduction resulting from integration. We assume that export prices increase to mimic an improvement of the terms of trade resulting from the integration of trading countries. Hence, our simulation results should not be taken as estimates of the impact of trade liberalization under GATT obligations or other agreements, but rather as likely conditions resulting from integration and its implications on specialization, pollution, and real income.[10]

Specifically, we decrease the *ad-valorem* tariffs, progressively to zero, from their reference levels (1997) to 60 per cent of these original levels in 2000, 30 per cent in 2005, and zero in 2010. Terms-of-trade improvements are expressed as an increase in observed world prices for exports by 5 per cent in 2000, 8 per cent in 2005, and 10 per cent in 2010.

We consider analogous regional integration and liberalization scenarios with NAFTA and MERCOSUR countries. Disaggregated data on trade flows allow us to consider these alternative trade integration scenarios. In these two other trade scenarios, we remove tariffs and increase export prices following a similar progression as in the previous scenario, but only with respect to trading partners which are members of these two regional agreements. Our objective is to impose a sizeable trade shock on the Chilean economy to estimate changes in sectoral composition of production and trade following a more selective trade integration. These changes determine the pollution emitted and induced by the outward trade orientation. The MERCOSUR scenario also introduces a 10 per cent decrease in the price of imported natural gas from Argentina, which affects the relative price of energy inputs.

The last group of reform scenarios combines the first two types of reforms to investigate the implications of co-ordinated trade and environment policies. Joint trade and environmental reforms, lead to efficiency gains because two policy instruments allow to reduce both trade and environmental distortions (Copeland, 1994; and Beghin, Roland-Holst, and van der Mensbrugghe, 1997). Recall we want to investigate the effect

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[9] Taxing all pollutants simultaneously raises difficulties. First, tracing the effect of any single tax on resource allocation becomes impossible. Second, several tax combinations lead to the same decrease in all pollutants, but with different implications on sectoral allocation, consumption and trade.

[10] We thank Randy Wigle for this cautionary note

of such joint reform on sectoral allocation, trade, and pollution abatement. When border distortions have been removed (domestic border prices are equal to world prices) the incentives to import or change input mixes to abate pollution in production have been altered, compared to the case of the single environmental reform. The differences in the incentive structures lead one to expect contrasting results concerning the indirect abatement achieved via complementarity and substitution among emission types, which occurs under the two scenarios. All three sets of scenarios maintain tax revenue neutrality.

Results from policy reform simulations

Results follow the sequence of the three reform scenarios: environmental tax reform, trade integration (unilateral, NAFTA, and MERCOSUR), and then combined trade integration and environmental protection. We narrate salient results of the simulations in aggregate below. Table 2 sequentially shows the effects of the three scenarios on pollution emissions for the economy and for Santiago. Table 3 shows how pollution in Santiago affects the health status of its population for the three scenarios. Table 4 shows the estimated valuation of their health impact.

Effluent taxes

All effluent taxes but the one on BIOAIR have a negative impact on growth. These effects are small (less than 1 per cent), except for the tax on toxic emissions, BOD emissions, and bio-accumulative emissions in water which have a larger impact in absolute value. The pollution tax on BIOAIR has a very small positive impact on aggregate output. Hence, the strong tendency to have a reduction of aggregate output with budget neutral environmental taxes indicates that these policy reforms 'do not pay' for themselves in the narrow efficiency sense (Goulder, 1995). The effects of these taxes on other aggregate measures of economic activity tend to be small as well, with the same exception of the tax on BIOWAT. With the latter, trade decreases by about 9 per cent and investment decreases by 23 per cent. The moderate aggregate output effect of the environmental taxes dissimulates substantial variations at the disaggregated sectoral level and reallocation of resources across sectors.

Next we look at noticeable sectoral output effects, that is, substantial changes in output occurring in some of the 72 disaggregated sectors included in the model. For the first four taxes (all three toxics, BIOAIR), fish and seafood output increase significantly but mining activities decrease sharply. The tax on BIOWAT has a negative effect on virtually all sectors, and it especially has a strong effect on iron, coal, and basic metals. Aggregate trade contracts with the effluent taxes. At the disaggregated sectoral levels, trade effects are mixed. Importing is a way to abate pollution occurring in production, and exporting more reduces the pollution linked to consumption. These sectoral effects are moderate.

As indicated by table 2, pollution abatement induced by each effluent tax is diverse. Strong complementarities are observed in several subsets of the 13 effluent types, despite the clear possibility of substitution among pollution emissions implied by our model since we do not impose any

Table 2. *Impact of environmental policy reform on national effluent emissions and Santiago ambient pollution*

Table 2a. *Impact of environmental policy reform*

	TOXAIR	*TOXWAT*	*TOXSOL*	*BIOAIR*	*BIOWAT*	*BIOSOL*	*SO_2*	*NO_2*	*Co_x*	*VOC*	*PART*	*BOD*	*TSS*
National effluent emissions					aggregate abatement of 25% by type of effluent emissions								
TOXAIR	−25.0%	−26.0%	−24.2%	0.0%	−10.9%	−10.2%	−2.1%	−2.1%	−1.0%	−4.0%	−2.7%	−24.1%	−0.5%
TOXWAT	−23.7%	−25.0%	−23.1%	−0.1%	−10.8%	−8.6%	−3.3%	−3.2%	−1.1%	−4.8%	−3.2%	−23.0%	−0.3%
TOXSOL	−25.7%	−26.8%	−25.0%	0.1%	−11.3%	−9.9%	−1.8%	−1.8%	−0.9%	−3.8%	−2.4%	−24.9%	−0.4%
BIOAIR	−2.3%	−3.0%	−1.9%	−25.0%	−9.4%	−0.8%	−12.7%	−12.4%	−6.8%	−14.7%	−14.0%	−1.8%	−2.5%
BIOWAT	−6.7%	−7.0%	−6.5%	−0.7%	−25.0%	−2.0%	−0.2%	−0.1%	−4.3%	−1.4%	−5.2%	−6.5%	−2.1%
BIOSOL	−30.6%	−29.7%	−28.6%	−0.4%	−11.8%	−25.0%	0.6%	0.3%	−1.6%	−2.5%	−2.6%	−27.8%	−1.0%
SO_2	−3.8%	−5.8%	−3.3%	−3.8%	−4.8%	−0.1%	−25.0%	−24.9%	−4.0%	−10.2%	−16.5%	−3.3%	0.5%
NO_2	−3.7%	−5.7%	−3.1%	−3.8%	−4.6%	−0.2%	−25.0%	−25.0%	−4.0%	−10.1%	−16.5%	−3.1%	0.5%
CO_x	−6.3%	−6.5%	−5.4%	−6.2%	−28.9%	−2.6%	−7.5%	−7.4%	−25.0%	−4.4%	−33.1%	−5.3%	−12.0%
VOC	−3.8%	−4.9%	−3.5%	−1.3%	−3.3%	−0.4%	−3.3%	−3.3%	−0.5%	−25.0%	−2.1%	−3.5%	0.1%
PART	−5.0%	−6.1%	−4.3%	−4.8%	−15.8%	−1.5%	−15.7%	−15.7%	−13.6%	−7.1%	−25.0%	−4.3%	−5.4%
BOD	−25.7%	−26.9%	−25.0%	0.1%	−11.4%	−9.5%	−1.9%	−1.8%	−0.9%	−3.8%	−2.4%	−25.0%	−0.4%
TSS	−12.1%	−10.7%	−10.7%	−9.3%	−52.9%	−6.6%	9.9%	9.9%	−46.6%	0.8%	−50.8%	−10.5%	−25.0%
Santiago concentrations													
Lead	−2.8%	−3.3%	−2.6%	−11.4%	−5.3%	−1.0%	−6.7%	−6.6%	−3.2%	−6.2%	−7.0%	−2.5%	−1.1%
SO_2	−2.0%	−3.4%	−1.6%	−2.6%	−3.9%	−0.4%	−17.8%	−17.7%	−2.8%	−7.5%	−11.6%	−1.6%	0.4%
NO_2	−2.0%	−3.6%	−1.6%	−2.9%	−4.2%	0.4%	−19.9%	−19.8%	−3.1%	−8.3%	−13.0%	−1.6%	0.5%
CO	−5.8%	−5.9%	−5.0%	−5.6%	−31.7%	−2.6%	−5.4%	−5.3%	−26.7%	−3.9%	−34.3%	−4.9%	−12.7%
VOC	−2.4%	−3.1%	−2.1%	−0.7%	−2.7%	−0.1%	−2.9%	−2.9%	−0.5%	−18.6%	−1.9%	−2.1%	0.1%
PM10	−4.5%	−5.5%	−3.8%	−4.7%	−18.8%	−1.4%	−14.3%	−14.2%	−15.4%	−7.0%	−27.0%	−3.8%	−6.2%
Ozone	−1.8%	−2.7%	−1.6%	−1.2%	−2.6%	0.1%	−7.4%	−7.3%	−1.1%	−12.4%	−4.8%	−1.6%	0.2%

Table 2. *Continued*

Table 2b. *Impact of trade liberalization and of coordinated NAFTA trade liberalization and environmental policy reform*

	Trade liberalization			*Combined NAFTA and environmental policy*					
	UNILIB	*NAFTA*	*MERCOSUR*	*BIOAIR*	*SO_2*	*NO_2*	*CO_x*	*VOC*	*PART*
National effluent emissions						25% reduction by type of			
TOXAIR	6.5%	2.4%	0.6%	2.4%	−0.1%	−0.1%	1.2%	−2.0%	−0.7%
TOXWAT	8.0%	2.4%	0.7%	2.3%	−1.4%	−1.4%	1.2%	−2.9%	−1.4%
TOXSOL	6.7%	2.4%	0.5%	2.5%	0.3%	0.3%	1.4%	−1.7%	−0.4%
BIOAIR	−6.0%	0.4%	−0.9%	−25.0%	−13.5%	−13.2%	−6.8%	−15.5%	−14.7%
BIOWAT	13.7%	3.3%	1.3%	2.6%	3.1%	3.2%	−1.3%	1.7%	−2.3%
BIOSOL	3.3%	1.2%	−0.3%	0.9%	1.1%	0.8%	−0.8%	−1.7%	−2.2%
SO_2	19.4%	2.8%	2.0%	−1.1%	−25.0%	−25.0%	−1.7%	−8.5%	−15.9%
NO_2	19.3%	2.9%	2.0%	−1.0%	−25.0%	−25.0%	−1.6%	−8.4%	−15.8%
CO_x	11.6%	1.6%	0.8%	−4.8%	−6.7%	−6.7%	−25.0%	−3.4%	−34.1%
VOC	11.5%	3.4%	1.2%	2.1%	−0.3%	−0.3%	2.9%	−25.0%	1.0%
PART	15.1%	2.4%	1.3%	−2.5%	−15.1%	−15.1%	−12.1%	−5.6%	−25.0%
BOD	7.0%	2.4%	0.6%	2.5%	0.1%	0.1%	1.3%	−1.8%	−0.5%
TSS	2.4%	1.3%	−0.6%	−8.2%	12.3%	12.3%	−47.9%	2.0%	−52.4%
Santiago concentrations									
Lead	0.8%	0.8%	0.4%	−10.8%	−6.6%	−6.5%	−2.5%	−5.9%	−6.8%
SO_2	14.3%	1.1%	1.7%	−1.6%	−18.4%	−18.3%	−2.1%	−7.1%	−12.0%
NO_2	15.8%	1.3%	1.9%	−1.6%	−20.5%	−20.5%	−2.2%	−7.8%	−13.3%
CO_x	11.5%	0.9%	0.8%	−4.8%	−4.9%	−4.8%	−27.6%	−3.5%	−35.9%
VOC	8.8%	2.3%	1.0%	1.6%	−0.9%	−0.9%	1.8%	−19.0%	0.1%
PM10	15.3%	1.6%	1.5%	−3.2%	−14.1%	−14.0%	−15.0%	−6.3%	−27.9%
Ozone	9.2%	1.6%	1.1%	0.4%	−6.5%	−6.5%	−0.3%	−12.5%	−3.8%

Table 2. *Continued*

Table 2c. *Impact of coordinated unilateral trade liberalization and environmental policy reform*

	TOXAIR	*TOXWAT*	*TOXSOL*	*BIOAIR*	*BIOWAT*	*BIOSOL*	*SO_2*	*NO_2*	*CO_x*	*VOC*	*PART*	*BOD*	*TSS*
National effluent emissions	Free trade and aggregate abatement of 25% by type of effluent												
TOXAIR	−25.0%	−27.2%	−24.0%	6.4%	−10.5%	−2.1%	2.4%	2.4%	4.2%	0.4%	1.3%	−24.0%	5.9%
TOXWAT	−22.5%	−25.0%	−21.6%	7.9%	−9.3%	0.8%	1.5%	1.7%	5.2%	0.6%	1.5%	−21.6%	7.5%
TOXSOL	−26.0%	−28.3%	−25.0%	6.7%	−11.1%	−1.7%	3.0%	3.0%	4.6%	0.9%	1.9%	−25.0%	6.1%
BIOAIR	−8.9%	−9.9%	−8.4%	−25.0%	−16.8%	−6.8%	−22.6%	−22.2%	−15.5%	−23.6%	−24.2%	−8.3%	−8.5%
BIOWAT	4.7%	3.8%	5.0%	13.1%	−25.0%	12.1%	12.9%	13.0%	7.4%	11.1%	6.5%	5.0%	11.3%
BIOSOL	−36.2%	−36.0%	−34.0%	−3.7%	−17.1%	−25.0%	−1.3%	−2.1%	−5.0%	−6.1%	−6.4%	−33.3%	−4.4%
SO_2	13.3%	10.0%	14.3%	16.2%	9.4%	19.3%	−25.0%	−24.8%	6.9%	1.7%	−13.7%	14.3%	20.0%
NO_2	13.5%	10.3%	14.5%	16.1%	9.6%	19.1%	−25.1%	−25.0%	6.9%	1.7%	−13.8%	14.5%	19.9%
CO_x	2.9%	2.0%	4.1%	6.8%	−24.9%	9.4%	−2.0%	−1.9%	−25.0%	4.1%	−34.8%	4.2%	−1.5%
VOC	6.4%	4.7%	7.0%	10.5%	5.8%	11.2%	5.8%	5.9%	10.3%	−25.0%	7.5%	7.0%	11.6%
PART	8.0%	6.0%	9.0%	11.2%	−6.7%	13.7%	−12.9%	−12.9%	−8.0%	−2.8%	−25.0%	9.1%	9.3%
BOD	−25.9%	−28.3%	−24.9%	7.1%	−11.1%	−0.9%	3.1%	3.2%	4.9%	1.2%	2.2%	−25.0%	6.5%
TSS	−13.6%	−12.4%	−11.9%	−4.9%	−59.6%	−3.4%	19.7%	19.5%	−58.9%	4.1%	−58.6%	−11.7%	−25.0%
Santiago concentrations													
Lead	−2.9%	−3.7%	−2.6%	−8.2%	−6.0%	−0.2%	−9.0%	−8.8%	−4.0%	−7.0%	−9.2%	−2.5%	−0.4%
SO_2	11.1%	8.7%	11.7%	12.2%	6.0%	14.9%	−17.6%	−17.3%	5.2%	1.1%	−9.4%	11.7%	14.9%
NO_2	12.6%	10.0%	13.4%	13.4%	6.8%	16.3%	−19.8%	−19.6%	5.7%	1.2%	−10.7%	13.4%	16.4%
CO_x	3.5%	2.9%	4.7%	7.2%	−29.1%	9.5%	1.4%	1.6%	−27.9%	4.6%	−36.2%	4.7%	−2.5%
VOC	5.6%	4.4%	6.1%	8.2%	4.1%	8.8%	3.7%	3.7%	7.5%	−18.5%	5.1%	6.1%	8.9%
PM10	9.1%	7.3%	10.1%	11.6%	−10.8%	14.3%	−10.5%	−10.3%	−10.7%	3.1%	−27.4%	10.2%	8.5%
Ozone	6.6%	5.2%	7.0%	8.2%	4.2%	9.3%	−4.0%	−3.8%	5.6%	−9.8%	−0.4%	7.0%	9.4%

Table 3. *Impact of environmental policy reform on health endpoints for Santiago*

Table 3a. *Impact of environmental policy reform*

	TOXAIR	*TOXWAT*	*TOXSOL*	*BIOAIR*	*BIOWAT*	*BIOSOL*	*SO*$_2$	*NO*$_2$	*CO*$_x$	*VOC*	*PART*	*BOD*	*TSS*
							Aggregate abatement of 25% by type of effluent						
Premature mortality/ 100,000.Year	−3.8%	−4.9%	−3.2%	−4.0%	−14.4%	−0.8%	−15.3%	−15.2%	−11.7%	−7.2%	−22.4%	−3.1%	−4.3%
Premature mortality/ 1 million males age 40–59	−2.8%	−3.3%	−2.6%	−11.4%	−5.3%	−1.0%	−6.7%	−6.6%	−3.2%	−6.2%	−7.0%	−2.5%	−1.1%
RHA/year	−3.1%	−4.0%	−2.6%	−2.8%	−10.2%	−0.6%	−10.6%	−10.5%	−7.8%	−9.9%	−15.2%	−2.6%	−2.8%
ERV/year	−4.5%	−5.5%	−3.8%	−4.7%	−18.8%	−1.4%	−14.3%	−14.2%	−15.4%	−7.0%	−27.0%	−3.8%	−6.2%
RAD/year	−4.5%	−5.5%	−3.8%	−4.7%	−18.8%	−1.4%	−14.3%	−14.2%	−15.4%	−7.0%	−27.0%	−3.8%	−6.2%
LRI/year (children < age 17)	−4.5%	−5.5%	−3.8%	−4.7%	−18.8%	−1.4%	−14.3%	−14.2%	−15.4%	−7.0%	−27.0%	−3.8%	−6.2%
Asthma attacks/year (asthmatics)	−2.4%	−3.3%	−2.1%	−1.9%	−6.1%	−0.2%	−8.9%	−8.8%	−4.2%	−11.2%	−9.6%	−2.1%	−1.2%
Respiratory symptoms/ year	−3.6%	−4.5%	−3.1%	−3.4%	−13.2%	−0.9%	−11.9%	−11.8%	−10.5%	−8.9%	−19.3%	−3.0%	−4.0%
Chronic bronchitis/year	−4.5%	−5.5%	−3.8%	−4.7%	−18.8%	−1.4%	−14.3%	−14.2%	−15.4%	−7.0%	−27.0%	−3.8%	−6.2%
MRAD/year	−1.8%	−2.7%	−1.6%	−1.2%	−2.6%	0.1%	−7.4%	−7.3%	−1.1%	−12.4%	−4.8%	−1.6%	0.2%
Respiratory symptoms/ year (children)	−2.0%	−3.4%	−1.6%	−2.6%	−3.9%	0.4%	17.8%	−17.7%	−2.8%	−7.5%	−11.6%	−1.6%	0.4%
Chest discomfort episodes/year	−2.0%	−3.4%	−1.6%	−2.6%	−3.9%	0.4%	−17.8%	−17.7%	−2.8%	−7.5%	−11.6%	−1.6%	0.4%
Respiratory symptoms/ year (adults)	−2.0%	−3.6%	−1.6%	−2.9%	−4.2%	0.4%	−19.9%	−19.8%	−3.1%	−8.3%	−13.0%	−1.6%	0.5%
Eye irritations/year (adults)	−1.8%	−2.7%	−1.6%	−1.2%	−2.6%	0.1%	−7.4%	−7.3%	−1.1%	−12.4%	−4.8%	−1.6%	0.2%
Headaches/year	−5.8%	−5.9%	−5.0%	−5.6%	−31.7%	−2.6%	−5.4%	−5.3%	−26.7%	−3.9%	−34.3%	−4.9%	−12.7%
IQ decrements	−2.8%	−3.3%	−2.6%	−11.4%	−5.3%	−1.0%	−6.7%	−6.6%	−3.2%	−6.2%	−7.0%	−2.5%	−1.1%
Cases of hypertension/ 1 million males age > 20	−2.8%	−3.3%	−2.6%	−11.4%	−5.3%	−1.0%	−6.7%	−6.6%	−3.2%	−6.2%	−7.0%	−2.5%	−1.1%
Non-fatal heart attacks/ 1 million males age 40–59	−2.8%	−3.3%	−2.6%	−11.4%	−5.3%	−1.0%	−6.7%	−6.6%	−3.2%	−6.2%	−7.0%	−2.5%	−1.1%

Table 3. *Continued*

Table 3b. *Impact of trade liberalization and of coordinated NAFTA trade liberalization and environmental policy reform*

	Trade liberalization			*Combined NAFTA and environmental policy*					
	UNILIB	*NAFTA*	*MERCOSUR*	*BIOAIR*	*SO_2*	*NO_2*	*CO_x*	*VOC*	*PART*
					25% reduction by type of effluent				
Premature mortality/100,000.year	15.0%	1.4%	1.5%	−2.7%	−15.4%	−15.3%	−11.2%	−6.5%	−23.1%
Premature mortality/1 million males age 40–59	0.8%	0.8%	0.4%	−10.8%	−6.6	−6.5%	−2.5%	−5.9%	−6.8%
RHA/year	12.0%	1.6%	1.3%	−1.3%	−10.1%	−10.0%	−6.9%	−9.6%	−15.1%
ERV/year	15.3%	1.6%	1.5%	−3.2%	−14.1%	−14.0%	−15.0%	−6.3%	−27.9%
RAD/year	15.3%	1.6%	1.5%	−3.2%	−14.1%	−14.0%	−15.0%	−6.3%	−27.9%
LRI/year (children < age 17)	15.3%	1.6%	1.5%	3.2%	−14.1%	−14.0%	−15.0%	−6.3%	−27.9%
Asthma attacks/year (asthmatics)	10.5%	1.6%	1.2%	−0.4%	−8.1%	−8.1%	−3.0%	−11.1%	−9.0%
Respiratory symptoms/year	13.2%	1.6%	1.3%	−2.0%	−11.4%	−11.4%	−9.7%	−8.4%	−19.5%
Chronic bronchitis/year	15.3%	1.6%	1.5%	3.2%	−14.1%	−14.0%	−15.0%	−6.3%	−27.9%
MRAD/year	9.2%	1.6%	1.1%	0.4%	−6.5%	−6.5%	0.3%	−12.5%	−3.8%
Respiratory symptoms/year (children)	14.3%	1.1%	1.7%	−1.6%	−18.4%	−18.3%	−2.1%	−7.1%	−12.0%
Chest discomfort episodes/year	14.3%	1.1%	1.7%	−1.6%	−18.4%	−18.3%	−2.1%	−7.1%	−12.0%
Respiratory symptoms/year (adults)	15.8%	1.3%	1.9%	−1.6%	−20.5%	−20.5%	−2.2%	−7.8%	−13.3%
Eye irritations/year (adults)	9.2%	1.6%	1.1%	0.4%	−6.5%	−6.5%	0.3%	−12.5%	−3.8%
Headaches/year	11.5%	0.9%	0.8%	−4.8%	−4.9%	−4.8%	−27.6%	−3.5%	−35.9%
IQ decrements	0.8%	0.8%	0.4%	−10.8%	−6.6%	−6.5%	−2.5%	−5.9%	−6.8%
Cases of hypertension/1 million males age > 20	0.8%	0.8%	0.4%	−10.8%	−6.6%	−6.5%	−2.5%	−5.9%	−6.8%
Non-fatal heart attacks/1 million males age 40–59	0.8%	0.8%	0.4%	−10.8%	−6.6%	−6.5%	−2.5%	−5.9%	−6.8%

Table 3. *Continued*

Table 3c. *Impact of coordinated trade liberalization and environmental policy reform*

	TOXAIR	*TOXWAT*	*TOXSOL*	*BIOAIR*	*BIOWAT*	*BIOSOL*	SO_2	NO_2	CO_x	*VOC*	*PART*	*BOD*	*TSS*
Free trade and aggregate abatement of 25% by type of effluent													
Premature mortality/100,000/year	9.7%	7.7%	10.6%	11.8%	−5.8%	14.4%	−12.6%	−12.4%	−5.9%	2.5%	−22.0%	10.6%	10.4%
Premature mortality/1 million males age 40–59	−2.9%	−3.7%	−2.6%	−8.2%	−6.0%	−0.2%	−9.0%	−8.8%	−4.0%	−7.0%	−9.2%	−2.5%	−0.4%
RHA/year	7.7%	6.2%	8.5%	9.8%	−2.8%	11.6%	−7.0%	−6.9%	−2.0%	−3.8%	−13.0%	8.5%	9.0%
ERV/year	9.1%	7.3%	10.1%	11.6%	−10.8%	−14.3%	−10.5%	−10.3%	−10.7%	3.1%	−27.4%	10.2%	8.5%
RAD/year	9.1%	7.3%	10.1%	11.6%	−10.8%	14.3%	−10.5%	−10.3%	−10.7%	3.1%	−27.4%	10.2%	8.5%
LRI/year (children < age 17)	9.1%	7.3%	10.1%	11.6%	−10.8%	14.3%	−10.5%	−10.3%	−10.7%	3.1%	−27.4%	10.2%	8.5%
Asthma attacks/year (asthmatics)	7.1%	5.6%	7.7%	8.9%	1.0%	10.4%	−5.3%	−5.2%	2.1%	−7.0%	−6.2%	7.7%	9.2%
Respiratory symptoms/year	8.2%	6.6%	9.0%	10.4%	−5.6%	12.5%	−8.2%	−8.0%	−5.0%	−1.4%	−18.0%	9.1%	8.8%
Chronic bronchitis/year	9.1%	7.3%	10.1%	11.6%	−10.8%	14.3%	−10.5%	−10.3%	−10.7%	3.1%	−27.4%	10.2%	8.5%
MRAD/year	6.6%	5.2%	7.0%	8.2%	4.2%	9.3%	−4.0%	−3.8%	5.6%	−9.8%	−0.4%	7.0%	9.4%
Respiratory symptoms/year (children)	11.1%	8.7%	11.7%	12.2%	6.0%	14.9%	−17.6%	−17.3%	5.2%	1.1%	−9.4%	11.7%	14.9%
Chest discomfort episodes/year	11.1%	8.7%	11.7%	12.2%	6.0%	14.9%	−17.6%	−17.3%	5.2%	1.1%	−9.4%	11.7%	14.9%
Respiratory symptoms/year (adults)	12.6%	10.0%	13.4%	13.4%	6.8%	16.3%	−19.8%	−19.6%	5.7%	1.2%	−10.7%	13.4%	16.4%
Eye irritations/year (adults)	6.6%	5.2%	7.0%	8.2%	4.2%	9.3%	−4.0%	−3.8%	5.6%	−9.8%	−0.4%	7.0%	9.4%
Headaches/year	3.5%	2.9%	4.7%	7.2%	−29.1%	9.5%	1.4%	1.6%	−27.9%	4.6%	−36.2%	4.7%	−2.5%
IQ decrements	−2.9%	−3.7%	−2.6%	−8.2%	−6.0%	−0.2%	−9.0%	−8.8%	−4.0%	−7.0%	−9.2%	−2.5%	−0.4%
Cases of hypertension/1 million males age > 20	−2.9%	−3.7%	−2.6%	−8.2%	−6.0%	−0.2%	−9.0%	−8.8%	−4.0%	−7.0%	−9.2%	−2.5%	−0.4%
Non-fatal heart attacks/1 million males age 40–59	−2.9%	−3.7%	−2.6%	−8.2%	−6.0%	−0.2%	−9.0%	−8.8%	−4.0%	−7.0%	−9.2%	−2.5%	−0.4%

Table 4. *Impact of environmental policy reforms on mortality and morbidity health*

Table 4a. *Impact of environmental policy reform*

	TOXAIR	*TOXWAT*	*TOXSOL*	*BIOAIR*	*BIOWAT*	*BIOSOL*	*SO_2*	*NO_2*	*CO_x*	*VOC*	*PART*	*BOD*	*TSS*
Health damages reductions	Aggregate abatement of 25% by type of effluent emission												
Mortality	−377.2	−459.8	−334.5	−1072.9	−996.5	−114.3	−1150.8	−1136.4	−719.6	−784.4	−1452.0	−328.9	−258.4
Morbidity	−104.8	−128.8	−89.2	−108.1	−409.8	−28.7	−336.9	−334.8	−330.7	−207.4	−592.1	−88.2	−130.7
Total in PPP$	−482.0	−588.6	−423.7	−1181.0	−1406.3	−143.1	−1487.7	−1471.2	−1050.3	−991.8	−2044.1	−417.0	−389.1
% of GDP BAU (4)	−0.16%	−0.20%	−0.14%	−0.40%	−0.47%	−0.05%	−0.50%	−0.49%	−0.35%	−0.33%	−0.69%	−0.14%	−0.13%
Impact of reform on market allocation													
Real GDP change (5)	−1.91%	−2.09%	−1.92%	0.03%	−7.61%	−0.42%	−0.20%	−0.19%	−0.07%	−0.45%	−0.18%	−1.91%	−0.01%
Total gains (5)–(4)	−1.75%	−1.89%	−1.77%	0.43%	−7.14%	−0.37%	−0.30%	−0.30%	−0.29%	−0.12%	−0.50%	−1.77%	0.12%

Table 4b. *Impact of trade liberalization and of coordinated NAFTA trade liberalization and environmental policy reform*

	Trade liberalization			*Combined NAFTA and environmental policy*					
	UNILIB	*NAFTA*	*MERCOSUR*	*BIOAIR*	*SO_2*	*NO_2*	*CO_x*	*VOC*	*PART*
Health damages reductions				25% reduction by type of effluent					
Mortality	657.9	125.1	90.6	−971.9	−1143.6	−1130.9	−648.5	−729.8	−1464.9
Morbidity	363.2	40.8	36.1	−70.2	−328.2	−327.1	−315.1	−191.3	−605.6
Total in PPP$	1021.1	165.9	126.6	−1042.2	−1471.7	−1458.0	−963.6	−921.1	−2070.5
% of GDP BAU (4)	0.34%	0.06%	0.04%	−0.35%	−0.49%	−0.49%	−0.32%	−0.31%	−0.69%
Impact of reform on market allocation									
Real GDP change (5)	4.86%	1.40%	0.52%	1.44%	1.17%	1.18%	1.33%	0.89%	1.19%
Total gains (5)–(4)	4.52%	1.35%	0.48%	1.79%	1.66%	1.67%	1.65%	1.20%	1.88%

Table 4. *Continued*

Table 4c. *Impact of coordinated unilateral trade liberalization and environmental policy reform*

	TOXAIR	*TOXWAT*	*TOXSOL*	*BIOAIR*	*BIOWAT*	*BIOSOL*	*SO_2*	*NO_2*	*CO_x*	*VOC*	*PART*	*BOD*	*TSS*
Health damages reductions							Free trade and aggregate abatement of 25% by type of effluent						
Mortality	151.5	12.4	214.8	−190.1	−710.6	560.8	−1219.8	−1199.3	−559.3	−462.8	−1611.6	220.7	384.7
Morbidity	219.1	174.8	243.2	277.5	−210.7	341.9	−241.3	−237.1	−199.7	16.2	−580.1	244.5	220.4
Total in PPP$	370.6	187.2	458.0	87.4	−921.3	902.8	−1461.0	−1436.4	−759.1	−446.6	−2191.7	465.2	605.0
% of GDP BAU (4)	0.12%	0.06%	0.15%	0.03%	−0.31%	0.30%	−0.49%	−0.48%	−0.25%	−0.15%	−0.74%	0.16%	0.20%
Impact of reform on market allocation													
Real GDP change (5)	2.57%	2.27%	2.59%	4.89%	−7.09%	4.50%	4.48%	4.49%	4.75%	4.17%	4.50%	2.59%	4.85%
Total gains (5)–(4)	2.44%	2.21%	2.44%	4.86%	−6.78%	4.20%	4.97%	4.97%	5.01%	4.32%	5.23%	2.44%	4.65%

fixed proportions between output and emissions. An increase in the tax on one effluent induces a decrease in another effluent level. All toxics are such a group, so are all bio-accumulative emissions, and NO_2, SO_2, and PART (PM-10). More intriguing is the presence, in the aggregate, of substitution possibilities among effluents. For example, SO_2 and NO_2 are substitutes for TSS.

The tax rates implied by the targeted decrease in emissions are realistic, when expressed in *ad valorem* equivalent of the producer price. On average, the pollution tax per unit of sectoral output is 4 per cent or less for all 13 scenarios. The individual tax rates (per sector and by effluent) vary from zero to less than 15 per cent for all 13 scenarios, except for the scenario targeting reductions in VOC. In the latter scenario the pollution tax rate on wine and liquors and furniture products jumps above 50 and 35 per cent, respectively. These high rates are caused by the fact that these two sectors account for most of the VOC pollution in production.

The decomposition of the abatement reveals that the composition effect seems overwhelming both in the abatement in production and in consumption. The effect is more substantial in production than in consumption, that is, imports substitute for domestic output in pollution-intensive sectors. The technical effect in production is moderate, and the scale effect is marginal for most pollutants, except in the case of the BIOWAT tax (production scale effect of –8.1 per cent).

The impact of the effluent taxes on the concentration in Santiago is diverse and generally follows the complementarity patterns observed for emissions. As shown in table 2, taxes on VOC, SO_2, NO_2, and PART provide significant decreases in lead (between 6 and 7 per cent). The taxes on BIOAIR and BIOWAT decrease lead concentrations as well. The tax on BIOWAT has negative and sometime large effects on other concentrations as well—remember it is the tax which has the largest negative scale effects among the effluent taxes. Air pollution taxes also produce similar concentration patterns. Emission taxes on either NO_2, SO_2, or PM-10 leads to a substantial decrease in the other two, and some decrease in COx. Taxes on COx and VOC also achieve substantial decreases in concentration in Santiago through a reduction of energy use and through a reduction in ozone. The other taxes have marginal impact on most of the concentrations.

In table 3, the health endpoint changes are striking for the taxes on SO_2, NO_2, and PM-10. Premature mortality reductions are between 15 and 22 per cent. With these three taxes, most endpoints show improvements with decreases of morbidity between 10 and 27 per cent for most of the morbidity measures.

Table 4 presents the health damages reductions induced by each environmental tax. The tax on PM-10 induces a decrease in monetary damages equivalent to 0.69 per cent of the BAU 2010 GDP; taxes on SO_2 and NO_2 reduce damages by an amount equivalent to about 0.50 per cent of BAU 2010 GDP. The latter taxes induce net gains, as approximated by the loss of aggregate income plus the reduction in damages, so does the tax on BIOAIR. These results show the importance of accounting for non-market benefits when considering the impact of environmental taxes. The estimated welfare gains are lower-bound estimates because the decreases in morbidity and mortality are only applied to Santiago's population. Hence, we find evidence of a net welfare gain (a double dividend) when accounting for health damages. These gains are rather small in part because we only value health benefits for a subset of the Chilean population.

Trade integration

Unilateral integration with world markets induces the largest increase in GDP (4.86 per cent), followed by regional integration via NAFTA (1.4 per cent) and MERCOSUR (0.52 per cent). These gains are small—they represent the relative gains over ten years. These small changes originate in the outward-orientation Chile has been following; large gains from liberalization have already occurred. Nevertheless these reforms have more significant positive impacts on aggregate trade and aggregate gross investment.

Moving to disaggregated sectoral output effects, the three trade reforms exhibit sharp contrast. The unilateral trade reform stimulates the output of fruit, forestry, iron, other mining, food processing, wood products, paper, and petroleum refining. Conversely, petroleum and gas production, chemicals, copper, fishmeal, glass, and other manufacturing contract with undistorted trade. With NAFTA integration, fruit, agricultural services, other mining, food processing except fishmeal, wine and liquor, would expand significantly, whereas copper, iron, and paper would decrease. Hence, NAFTA integration departs significantly from integration with all partners in terms of international specialization. MERCOSUR integration does not induce any strong effect, except for a major increase in food processing other than fishmeal, transportation material, and a decrease in iron and copper production.

The trade effects of these reforms are as follows. The unilateral reform induces major increases in virtually all sectoral imports and exports, except for imports of chemicals, glass, and other manufacturing and exports of fishmeal and copper. NAFTA integration has a smaller effect on trade than unilateral reform. There are noticeable export increases for food processing, wine, textile, and apparel, and decreases for iron, copper, forestry, and fishmeal. Imports of agriculture, livestock, forestry, mining sectors, and wood products expand as well. Finally, the MERCOSUR integration induces increases in imports of agricultural products, iron, oils, sugar, tobacco, petroleum refining, and metals; imports of fish would decrease. On the export side, substantial reductions occur in exports of fishmeal, iron, copper, and seafood; but food processing, chemicals, plastics, and printing expand significantly. The endogenous world price assumption for fishmeal and copper accentuates the contraction of these two industries that occurred already under the small-country assumption.

The pollution implications of these trade reforms are contrasting as shown by table 2. Unilateral integration is pollution intensive; for example, NO_2, SO_2, and PM-10 have elasticity with respect to GDP between 3 and 4 under this scenario. By contrast, NAFTA has elasticity values around 2 and 2.2 respectively, for the same effluents. The moderate expansion of pollution under MERCOSUR is matched by a moderate GDP expansion resulting in a air pollution-intensive integration. However, MERCOSUR and unilateral integrations bring a decrease in BIOAIR induced by cheaper imports of natural gas. The trade diversion of NAFTA integration mitigates emissions, relative to the other two trade integration scenarios. This is an unexpected if not overlooked insight on trade diversion in the presence of externalities. The NAFTA scenario produces strong composition effects in production, outweighing the scale expansion induced by NAFTA. By contrast, the unilateral integration *vis-à-vis* all partners induces higher intensities in SO_2, NO_2, and PART (PM-10) via strong technical effects towards pollution-intensive input combinations. In addition to large increase in SO_2, NO_2, and PART, unilateral integration brings increases for all toxics, BIOWAT, COx, VOC, and BOD. These increases are observed after ten years of expected growth and hence do not represent anything dramatic.

For the health end-points in Santiago, the unilateral integration scenario has negative consequences for both mortality and almost all measures of morbidity as shown in table 3. Premature mortality due to PM-10, ozone, and SO_2 increases by 15 per cent and premature death in males of age 40–59 due to lead increases marginally. Morbidity increases are significant except IQ decrements, hypertension, and non-fatal heart attacks. NAFTA and MERCOSUR induce marginal increases in the health end-points. The damages associated with the health incidences are substantial for the unilateral trade integration. As suggested by table 4, the damages represent about 8 per cent of the aggregate income gains induced by trade integration (damages as per cent of gains in GDP). By contrast the damages under the NAFTA scenario are moderate due to the small deterioration of the average health status in Santiago.

Co-ordinated trade integration and environmental protection

We first combine NAFTA integration and effluent taxes on air pollutants. Then, we consider unilateral trade integration co-ordinated with an effluent tax on one pollutant at the time. The effluent taxes are designed as in the first set of scenarios on environmental reforms, that is, incremental and leading to a 25 per cent decrease in emissions of the taxed effluent with respect to their BAU levels. The tax rates corresponding to these reforms are slightly higher than in the environmental reforms alone. The average tax rates on pollution, expressed in per cent of the producer price per unit of output, do not exceed 6 per cent. With trade integration, the pollution expansion requires higher tax rates than those reached under the environmental reform alone, in order to go back to a pollution level corresponding to a 25 per cent decrease with respect to the BAU level. With these higher rates, substitution/complementarity relationships between pollutant types are exacerbated.

The aggregate effect of the combined reforms (NAFTA *cum* effluent tax) is small in general, but it is positive on real income in all cases. This positive real income effect suggests that with this larger policy menu (trade and environmental distortions), the environmental reform pays for itself, even before accounting for the associated health benefits. The aggregate effects also differ according to the pollutant considered. For example, the effluent tax on COx has practically no effect on aggregate measures, whereas, the tax on VOC has a negative impact on production and consumption. As shown in table 2, the pollution abatement figures, including the multiplier effects of the tax on pollutants that are not directly targeted by the tax, are similar to the abatement figures obtained under the environmental reforms alone. The indirect abatement of pollutants other than the targeted one does not have to be because changing border prices affects specialization and hence pollution. This result is due to the fact that NAFTA integration has a mitigated impact on the Chilean environment.

The impact of co-ordinated unilateral trade integration with environmental taxes appears almost additive on aggregate output, trade and consumption. This is a recurrent result in this type of simulation exercise (Lee and Roland-Holst, 1997; Beghin, Roland-Holst, and van der Mensbrugghe, 1995). However as suggested by table 4, not all scenarios lead to an environmental benefit and here this additivity breaks down. This result is caused by substitution among emissions groups, which are exacerbated when trade distortions are removed. A tax on one pollutant group increases emissions of another pollutant group and associated health damages. The scenarios involving unilateral trade integration and a tax on BIOWAT, SO_2, NO_2, COx, VOC, and PART (PM10) induce an environmental dividend. The other combined scenarios do not. All co-ordinated reforms pay for themselves in the narrow sense of the double dividend, except the free trade *cum* BIOWAT tax reform, which leads to a negative GDP effect.

Aggregate trade expands less under the co-ordinated reforms than under simple unilateral trade integration, although some sectoral import induced by the latter reform grow even more under the co-ordinated scenario because imports are a way to abate pollution. For instance, fish imports are larger under the combined scenario than under unilateral trade integration alone. The inventory of emissions duplicates several patterns reached under the single effluent tax reform. All three toxic effluents are complementary to each other, so are the three bio-accumulative effluents and so are air pollutants too. Nevertheless air pollutants (SO2, NO2, VOC, PM-10, and COx) become substitutes for toxics and bio-accumulative emissions in water and soil. This substitution is caused by a selective increase in pollution mostly via a composition effect. The economy specializes in the goods cheaper to produce and induces a sharp increase in the untaxed types of pollution.

In table 3, the urban health impact of the co-ordinated reforms reflects these substitutions between broad groups of pollutants. Mortality due to air pollution increases dramatically under the combined scenarios involving toxics and some of bio-accumulative pollution, because the emissions of PM-10, SO_2, and NO_2 are stimulated. Similarly, the morbidity induced by SO_2, NO_2, PM-10, and COx increases under the same combined scenarios. As shown in table 4, damages reductions under co-ordinated reforms tend to be less substantial than under the environmental tax alone, because of the substitution forces at work among pollutant types. There is one exception. The reform combining free trade and the tax on PART induces a sharper decrease in premature mortality because free trade allows to substitute natural gas for gasoline at a lower relative price than under the PART reform alone. When we compare the co-ordinated reforms to unilateral trade integration, all combined scenarios exhibit higher real income levels, inclusive of health damages. For example, the tax on PM-10 combined with unilateral trade integration induces net welfare gains, which are 16 per cent higher than the net gains under trade integration alone.

Conclusions

This paper seeks to elucidate linkages between trade, environment, and public health status in an outward-oriented economy. From our results, it is apparent that such linkages are quite complex, and sound policy making will require the type of information produced in our investigation. Policies in all three areas are clearly interdependent, and better co-ordination could reduce the social and economic costs of economic growth and environmental mitigation. More detailed empirical work is needed, however, to support such policies.

Trade integration scenarios offer different outcomes in terms of growth, international division of labour and environmental consequences. Economic integration into NAFTA and MERCOSUR is relatively benign to the environment and NAFTA integration has small pollution elasticity with respect to the trade-induced growth. World trade integration via unilateral trade liberalization, with no pollution abatement policy, induces higher growth and patterns of specialization more adverse towards the environment, leading to detrimental impacts on public health in Santiago and considerable monetary damages associated with the negative health impact.

Considering effluent taxes alone, the abatement of three pollutants, SO2, NO2, and PM-10 achieves the largest decrease in both mortality and morbidity in Santiago. Health damage reduction under the PART reform exceeds the foregone aggregate real income and corresponds to a net welfare gain to the Chilean economy. Co-ordinated scenarios are well grounded in economic theory and represent the best of both worlds (efficiency gains from trade and protected environment); they are characterized by economic expansion and decreases in the emissions of the targeted pollutant as well as its polluting 'complements'. Nevertheless, emissions of untaxed substitute pollutants increase considerably. These strong substitutions have a negative impact on urban health, with notable increases in mortality and morbidity when toxic and bio-accumulative pollutants are the environmental targets. This is a result specific to our investigation of Chile. By contrast, our analysis of trade and environment linkages in Mexico suggests complementarity between effluent types (Beghin, Roland-Holst, and van der Mensbrugghe, 1995).

The observed substitutability among pollutant types under trade integration and its implications for urban health raises two additional co-ordination and targeting issues. The first one is the co-ordination of environmental programs targeting subgroups of pollutants (for example, toxic, bio-accumulative, air criteria pollutants). Given the substantial substitutability arising between these groups with trade integration, we suggest an integrated approach to environmental reform encompassing all major groups of pollutants. Several taxes would then be necessary to avoid unintended environmental degradation or negative health consequence. The other issue is the hopeful observation that strong complementarities exist within some groups of pollutants and that a policy targeting any pollutant within a group would achieve substantial abatement in most emission types included in the group. This finding is common to most of our case studies and emerges as an empirical regularity in these linkages.

Another regularity shared by this study and the other case studies using the same methodology is the relatively low cost of pollution abatement in terms of foregone aggregate income. In this specific case of Chile and Santiago, we establish this result in terms of welfare. The monetary damages equivalent to the health impact of air pollution are greatly reduced by environmental taxes, especially by the tax on PM-10, NO_2, and SO_2, such that the welfare gains exceed the loss of GDP induced by the taxes. A net welfare gain emerges. This statement should be qualified because the resource reallocation implied by the effluent taxes is substantial on a sectoral basis and we do abstract from explicit adjustment costs.

Finally, we find that revenue-neutral environmental taxes on air pollution induce health benefits, which are larger than the net efficiency loss induced by these new taxes. We also establish that revenue-neutral coordinated policy reforms, in which trade and air-pollution distortions are both reduced, increase real income in Chile. In the latter context, reducing PM-10, NO_2, and SO_2 combined with a removal of trade distortions, induces both efficiency and environmental benefits.

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