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The trade and environment nexus in Mexican agriculture. A general equilibrium analysis

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Abstract

This paper analyzes linkages between growth, trade and the environment in Mexican agriculture with an empirical economy-wide model. The investigation considers trade liberalization, environmental policy reform, and their coordination. The analysis decomposes the change in pollution emission induced by changes in the sectoral composition of production, effects of technology on emission intensity, and aggregate scale effects. Outward orientation alone induces a contraction of aggregate agricultural output, but promotes growth and pollution in some agricultural sectors. Overall, free trade does not induce wholesale specialization in dirty agricultural activities. Environmental taxes on pollution emitted in agricultural sectors have a moderate negative impact on agricultural output, except for the tax on water-borne toxic chemicals. More liberal trade combined with targeted effluent taxes can achieve significant environmental mitigation and efficiency gains, but with the implication of a contraction of most agricultural sectors. © 1997 Elsevier Science B.V.

1. Introduction

The North American Free Trade Agreement (NAFTA) has intensified the controversy on the environmental impact of trade liberalization that had started with the Uruguay Round of the GATT. NAFTA has induced a debate and a series of papers on trade and environment linkages [1], which have been characterized by sometimes polar attitudes (pro-trade against pro-environment, see USHOR, 1991), and by the limited availability of solid empirical evidence on these linkages between trade and the environment. The Maquiladoras and agricultural sectors of Mexico have been at the center of the debate. [2] Grossman and Krueger (1992) provide a valiant effort to produce gross estimates of the impact of NAFTA on the Mexican environment. However, their study relies on simplifying assumptions (high sectoral aggregation, rudimentary modelling of pollution) precluding the derivation of more perceptive insights. Abler and Pick (1993) provide an interesting investigation of chemical intensification in Mexi-

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[1] See Beghin et al. (1994) for an up-to-date survey.

[2] See Johnstone (1995) for an analysis of the transborder pollution induced by Maquiladoras and of the environmental cooperation between the United States and Mexico.

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can agriculture, which suffers from the opposite shortcomings: the scope of the paper is limited to a few horticultural crops and fertilizer use in the state of Sinaloa. Harrison (1993) provides an investigation of the potential industrial flight from the United States to Mexico in manufacturing sectors which are environmentally sensitive, but abstracts from agriculture. To our knowledge, the empirical literature on trade and environment linkages, especially in agriculture, has not systematically examined the impact of environmental policy menus that could be combined with Mexico's outward orientation to remedy environmental degradation.

Our paper addresses these shortcomings and takes a middle ground approach between Grossman–Krueger's and Abler–Pick's to investigate trade and environment linkages in Mexican agriculture. Our analysis considers these linkages both at the aggregate and commodity levels and for a vector of pollution emissions. This study builds on and extends substantially our early analysis (Beghin et al., 1995) of the environmental implications of growth and trade opening in Mexico by focusing on the agricultural sector and its specific pollution problems. Agriculture is disaggregated into 22 sectors and pollution is represented by a vector of 13 effluents. Mexican agriculture exhibits high emission intensities for toxic chemicals in soil, water-borne toxic chemicals, SO_2, and NO_2, relative to other sectors in the economy. In terms of total emissions, agricultural sectors, and especially horticulture, contribute significantly to toxic chemicals in soil and water, SO_2, NO_2, CO, suspended particulates, Volatile Organic Compounds (VOC), and Biological Oxygen Demand (BOD) problems. Hence, the interaction between outward orientation and the environment is strong for agricultural sectors.

Trade liberalization alone induces a relative decline of aggregate agricultural output. We also consider environmental reforms to mitigate emissions of toxic chemicals released in water and soil, NO_2, and SO_2, which are the four key pollutants linked to agricultural activities. The analysis considers a sequence of three policy reforms. First, environmental taxes are considered alone, and their effects on agricultural output, trade and pollution abatement are evaluated. The next step is to consider trade liberalization alone. Trade distortions in place before the NAFTA and Uruguay Round accords are removed progressively over time, and these results serve to calibrate the expansionary effects of trade liberalization as well as their environmental implications. Many 'win–win' cases (efficiency gains, lower pollution) occur; for example, the production of most staple crops, which contribute to toxics release in water, decreases with free trade. A few cases of intensified environmental degradation arise. For example, horticulture, which contributes to toxics release in water, expands moderately.

In the last scenario, coordinated environmental and trade policies combine the two previous scenarios and show how they interact. These results indicate that the coordinated policies decrease even further the agricultural output of polluting sectors adversely affected by trade liberalization. For several sectors the combined policies mitigate each other's undesirable effects, such as pollution induced by trade and contractionary effects of pollution abatement. In the aggregate however, agriculture contracts with the joint coordinated reforms.

For the three reform scenarios, total agricultural output contracts, but with diverse effects in terms of sectoral composition. Hence, it is interesting to see how the sectoral composition has been altered by the reforms. It appears that outward-oriented trade policy, especially when combined with environmental taxes, would be stern for several agricultural sectors such as corn, beans, sorghum, and soybeans. Further, we discuss the changes in pollution emissions induced by the policy reforms by source of abatement in production. Abatement essentially occurs in production because the consumption of agricultural commodities is not pollution-intensive. [3] The representative agricultural producer abates by changing the output level of the various produced commodities

[3] Our model allows for abatement from both production and consumption. Aggregate output can decrease (scale effect), the composition of aggregate output may change (a composition effect), the input mix can be altered in most sectors (a technical effect). Consumers can substitute away from commodities which are pollution-intensive in consumption (a second composition effect) and can scale back their aggregate consumption (a second scale effect). Agricultural sectors are not pollution-intensive in consumption and the latter two effects are not reported in this paper.

(a combined composition and scale effect), and by changing the input mix to produce a given commodity (the technique effect). The three reform scenarios present contrasting results on the decomposition of pollution abatement. These differences are driven by the different price incentives implied by these three reforms. A unique distinctive feature of our model is to account for the abatement achieved by changing the input mix. Previous economywide models assume constant emission intensities by sector and in these models abatement can only occur by changing the sectoral composition of GNP or by scaling down aggregate economic activity.

In the specific context of the interaction between international trade and the environment in agriculture, a general equilibrium analysis is instrumental for several reasons. First, an economy-wide model allows us to assess the relative contribution of agriculture in total pollution emitted by all sectors—are agricultural sectors pollution 'hot-spots', if yes, for what effluent? Second, this approach is indispensable to determine the pollution abatement that should occur in agricultural sectors given an economy-wide abatement target. The effluent tax corresponding to the abatement target for a given effluent determines the distribution of abatement across sectors. Last, this approach enables us to evaluate how pollution is abated through multiple channels in production, consumption and trade. Partial equilibrium approaches could not encompass all these elements and linkages.

The paper is organized as follows. In Section 2, we present some important background information on Mexican agriculture, which motivates our analysis. Next, we describe the modelling approach, some of its key features and implied supply and demand elasticities. We follow with a presentation of the policy reform scenarios, and then, of the results. We discuss the impact of the reforms on aggregate real income, and output, trade and pollution in agricultural sectors. Then, we present our concluding remarks.

2. The integration of Mexican agriculture

Agriculture in Mexico has been affected by globalization of economic activities induced by a series of reforms undertaken the last 10 years (GATT membership, Uruguay Round of the GATT, NAFTA, the PROCAMPO reform, land reform). As suggested by Table 1, agricultural distortions, as measured by the producer subsidy equivalent of policy interventions, have been reduced dramatically for most crops in Mexico since the mid 1980s. In the early 1980's Mexico embarked on a unique unilateral domestic and trade policy reform which was required for joining the GATT. Then, Mexico introduced trade reforms induced by NAFTA and the Uruguay round, and finally, Mexico put in place a land reform and a new agricultural policy, PROCAMPO, which decouples income transfer and production in the farm sector. The land reform sanctions the emergence of the burgeoning land market and reduces the uncertainty on property rights and should also ease the access to credit for small farmers (Heath, 1992). These unprecedented changes have propelled the Mexican economy and its agriculture in world markets.

Table 1
Producer subsidy equivalent[a] for major Mexican agricultural commodities

Commodity	1986	1987	1988	1989	1990	1991	1992
Barley	71.35	74.94	58.94	45.17	46.99	23.13	11.34
Beef	6.49	7.53	−2.56	−5.03	−8.93	−15.69	−20.39
Corn	74.08	80.93	55.37	45.72	55.01	55.62	49.72
Eggs	7.82	5.14	11.49	−8.92	−12.09	−17.77	−23.89
Milk	−0.66	−1.79	−3.22	−5.94	−5.17	−5.34	−5.97
Pork	33.82	43.67	31.32	24.64	19.72	9.40	6.50
Poultry	30.09	25.83	20.41	13.19	12.67	6.48	0.18
Soybeans	66.17	7.50	35.92	52.82	42.92	44.45	38.53
Sorghum	84.44	68.20	51.63	41.84	24.69	25.91	18.05
Wheat	55.11	50.31	33.54	27.09	53.90	54.27	37.20

Source: USDA (1994).
[a]The Producer Subsidy Equivalent is a summary measure of income support through various market interventions expressed in percent of total farm income inclusive of direct payments. Policy coverage includes economy-wide policies such as overvalued exchange rates, border and output measures, input subsidies, marketing assistance, and indirect support via R&D and infrastructure. After 1992, the major form of support is through direct non-distorting payments. The PSE does not reflect the tarrification of quantitative trade barriers which are very high for some commodities.

Optimistic conjectures tend to see this kind of economic integration as bringing a more efficient allocation of resources and environmental improvements induced by economizing on inputs (see for example, The World Bank's World Development Report on the environment). However, concerns of intensification of agriculture and of environmental degradation resulting from this market integration of Mexican agriculture have been raised, but not thoroughly investigated (Runge, 1993; Garcia-Barrios and Garcia-Barrios, 1990). These two opposite views may be consistent, depending on which specific sector is considered.

Although the contribution of agriculture to the Mexican GDP is only about 8%, its contribution to merchandise exports is over 10% and rapidly growing especially within North America. For instance, in 1991 agricultural exports reached US$2.8 billions including US$2.5 billions to the united States, its major trade partner. Mexico exports many commodities, principally horticulture, livestock, coffee, cotton, sugar and cattle. The exports of horticulture and cattle and livestock are expected to expand with the world market integration.

The important grain and oilseed crops are barley, corn, sorghum, soybeans, and wheat. Corn and dry beans are the major traditional crops. Two-ways trade exists for most of these commodities, indicating the heterogeneity of these commodities compared to their U.S. substitutes. Mexico is a net importer of these grains and oilseed crops. As a whole, the agricultural sector is being transformed into a modern industry of large farms and traditional farmers have been exiting the sectors. The Mexican food-processing industry is also expanding and is internationally competitive, especially for processed fruits and vegetables. The derived demand for raw agricultural commodities is expected to grow substantially.

The major environmental concern related to Mexican agriculture is its intensified chemical use and eutrophication of ground water resulting from both livestock and fertilizer. Groundwater pollution is caused by fertilizer use and manure from livestock, which lead to dangerous nitrate concentrations in water. The presence of nitrate and phosphate in water contributes to eutrophication (excess of nutrient which eventually decreases the dissolved oxygen content of water or soil (OECD, 1994). Nitrogen from fertilizer and manure goes back to the atmosphere by volatilization, and leaches in soil and water. It is difficult to know the exact proportion of leaching and volatilization for Mexico, but data for the E.U. suggests that about 30% of the nitrogen content of manure goes back to the atmosphere, while up to 50% of soil nitrate end up in water under precarious conditions (sandy soils, heavy rainfalls and high water tables (Leuck, 1993). This process may take up to 30 years and is difficult to model.

In the aggregate, Mexican agriculture is less chemical intensive than the agriculture of other OECD members. The average application of about 73 kg of nitrogen from fertilizer per hectare, and about 95 kg of nitrogen per hectare from live cattle and swine, which in total, represents about 96 kg of residual nitrogen per hectare of crop land in Mexico (1987–1989). This is lower than the average residual nitrogen of 108 kg per hectare for the EU, and of 245 kg per hectare for the OECD prior to Mexico's membership (200 kg from fertilizer and 230 kg from manure per hectare).

The average aggregate fertilizer use per hectare in Mexican agriculture seems to be below EU guidelines on Maximum Allowable Residual nitrogen fixed at 170 kg per hectare. The residual is the sum of nitrogen use in fertilizer and nitrogen content of manure minus crop nitrogen retention. Another indicator is the maximum allowable concentration of the 1980 EC Drinking Water Directive, which consider 50 ppm of nitrate as safe. According to Leuck (1993), a consensus estimate is that the nitrate maximum allowable concentration corresponds to roughly 127 kg of residual nitrogen per hectare per year. Hence chemical use in Mexican agriculture, in aggregate, seems below that indicator.

Nevertheless, the more disaggregated nitrogen figures for horticulture violates these two EC/EU indicators corresponding to safe levels of nitrate in water. Data from FERTIMEX, the (former) national Mexican fertilizer manufacturer, and unpublished data from the Confederation of Agricultural Associations of the State of Sinaloa (CAADES) show that nitrogen applications on tomatoes, peppers, and cucumbers, are above the national aggregate figure, in between 290 and 440 kg per hectare for these three commodities (Abler and Pick, 1993). Total fertilizer application on these three crops is several fold the average national amount. Still, when compared to chemical use (fertilizer and pesticide) in Florida, Mexican horticulture is less intensive, since it uses less than half the chemicals that Florida horticultural farmers use. [4]

Pesticide and herbicide use is another source of environmental concern in Mexican agriculture. Scarce data preclude deriving precise figures, but available data on U.S. pesticide and herbicide imports to Mexico are available (Yang, 1994). Pesticide use, specially fungicide, is widespread in Mexican horticulture. There are also some discontinuous time-series data on total pesticide imports (Yang, 1994). These partial sources allow to identify patterns of increasing chemical use. For example, data on US pesticide imports to Mexico show an upward trend in fungicide and herbicide use.

The estimates of input-based pollution-intensities of Dessus et al. (1994) provide some stylized facts on the relative chemical intensity of agriculture in several countries. These estimates suggest that Mexican agriculture is about 50% less intensive in toxic chemicals released in water than its U.S. counterpart, that it is three and half times more intensive than U.S. agriculture for toxic chemicals released in soil, and about as intensive for SO_2 and NO_2 emissions. These estimates disaggregated for the 22 sectors analyzed in this paper, are shown in Table 3. The sectors with the highest intensities of toxic chemicals in soil are wheat, sorghum, soybeans, cattle, swine, sheep and goats, and poultry. For chemicals released in water, the following sectors have high intensities: corn, wheat, rice, beans, sorghum, barley, soybeans, sesame, cotton, sugar, coffee, tobacco, cocoa, and horticulture. For NO_2 and SO_2, the intensive sectors are tobacco and horticulture. In terms of total emissions, cattle is the largest contributor to chemicals in soil, horticulture is the largest contributor of chemicals in water, NO_2 and SO_2. Corn, wheat and sorghum are the next largest contributors of toxic chemicals in water (not reported).

[4] As noted by a referee, the comparison of chemical intensity of agriculture in Mexico and the United States should account for the difference in toxicity of the chemicals used, especially for pesticides.

3. The economy-wide model

The Trade and Environment Equilibrium Analysis (TEQUILA) model was developed by the OECD development Centre for its sustainable Development research program. We only describe the salient features of the model. Further information is contained in our technical paper (Beghin et al., 1996b). In spirit, the TEQUILA model is conventional because it reflects accepted beliefs and common wisdom on limited substitution possibilities in Mexican production and on household income responses. The parameter values in the TEQUILA model compares to those of previous economywide models of Mexico, such as Levy and van Wijnbergen (1995). The two striking features of the TEQUILA model concern its dynamic features and the modelling of pollution emissions linked to dirty inputs.

The TEQUILA model is recursive dynamic (each period is solved as a static equilibrium problem given an allocation of savings and expenditure on current consumption). It is multi-sectoral (92 sectors). Production is based on constant returns to scale technology and the structure of production consists of a series of nested CES functions. Final output is determined from the combination of (non-energy) intermediate inputs and a composite bundle of energy and value added (labor and capital). Non-energy intermediate inputs are assumed to be used in fixed proportions with respect to total non-energy intermediate demand. The energy-value-added bundle is further decomposed into a labor aggregate on the one hand, and a capital-energy bundle on the other. Labor demand is further decomposed into eight occupational categories. The labor input, by labor type, is assumed to be perfectly mobile across sectors, while capital is only partially mobile, reflecting differences in the transferability of capital equipment across sectors. Both wages and capital returns are determined by economy-wide equilibrium conditions. However, the labor supply curve is differentiated by labor type with each category growing exogenously at different rates over time. Different labor categories are imperfect substitutes. In any given period labor supply is predetermined like an endowment.

The capital-energy bundle is disaggregated into capital demand and demand for an energy aggregate.

Finally, the energy bundle is decomposed into different base fuel components. One of the key advantages of this type of production structure is that emissions are linked to intermediate consumption rather than final output. Substitution possibilities exist 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. a key feature of the TEQUILA model is the vintage structure of capital. The model assumes a putty/semi-putty production technology. Substitution possibilities of existing old capital with other inputs (labor, energy, intermediate inputs) are smaller than the corresponding substitution possibilities of new capital coming from the new investment pool, implying that acceleration of investment would allow producers more flexibility in reacting to emission taxes and decrease the need to reduce output to reduce emissions. Finally, capital includes land and machinery. there is emerging evidence that land is traded and rented; transactions have been taking places for a long time (Heath, 1992). Another factor motivating lumping machinery and land is the recent finding that Mexican farmers are much more diversified than previously thought (Taylor, 1994). Flexibility in land allocation decisions does exist. Further, the 1992 land tenure reform is expected to considerably increase the mobile nature of land in agriculture.

We use elasticity values in the multi-nesting of production decisions, from top nesting to bottom which reflect prevailing wisdom on plausible parameter values for developing economies, and in particular for Mexico (see Levy and van Wijnbergen (1995); Sadoulet and de Janvry (1995), Chapter 12). These values tend to be conservative estimates. This choice is motivated by our concern to overstate abatement possibilities achieved through substitution away from dirty inputs. The values are as follows. Between intermediate consumption and aggregate value added made of old capital, 0; between intermediate consumption and aggregate valued added including new capital, 0.5; within value added and between aggregate labor and aggregate energy cum old capital, 0.12; between aggregate labor and aggregate energy cum new capital, 1; within aggregate labor, and between any two category of labor, 0.4; between aggregate energy and old capital, 0; between aggregate energy and new capital, 0.8; within aggregate energy combined with old capital and between any two types of energy inputs, 0.25; between any two energy sources combined to new capital, 2.

These assumptions lead to the following comparative-static elasticities of supply for the 22 agricultural and 14 processing sectors. [5] In the very short run (no mobility of capital) own-price responses vary between 0.03 (oil-seed) and 0.51 (feed processing) across the 36 sectors of interest. When capital mobility is increased (intersectoral elasticity of capital transformation of 1), long run own-price supply elasticities vary between 1.4 and 5.5 with the exception of feed processing increasing to 10.7. With this exception in mind, it appears that the model exhibits plausible price responses.

Another dynamic element is productivity growth. There are efficiency factors for capital, labor (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.

In the case of fixed output-based effluent measures, abatement of pollution can only occur by reducing output. By contrast, the transformation from output to input-based pollution effluents in our analysis is based on the methodology of Dessus et al. (1994) who derived econometric estimates of these input-based effluents intensities by matching data from a social accounting matrix disaggregated at the 4-digit ISIC level to the corresponding IPPS pollution database of Martin et al. (1991) at The World Bank. Then, these input-based measures are deflated to be expressed in 1989 Mexican prices and converted to Mexican Pesos. Emissions are generated by both the final consumption and the intermediate use of polluting goods. In certain sectors, there is an autonomous component of emissions, which is directly linked to the level of output due to unusually

[5] It is difficult to provide accurate dynamic supply price elasticities because the mobility of capital is vintage dependent and the composition of old/new capital changes by sector and with policy scenarios. Hence, we provide comparative-static estimates of supply price-response corresponding to very short run and long run elasticities.

high effluent intensities. The important implication of this approach is that labor and capital can be substituted for dirty intermediate pollution to decrease the pollution intensity of output in any given sector, that is, the technique effect of Copeland and Taylor (1994).

Excise/effluent taxes are used to achieve pollution abatement. These taxes are measured as unit of currency per unit of emissions and are implemented as an excise tax tacked on to the producer price of the polluting commodity (the tax per unit of effluent times the effluent intensity of the commodity). Consumers of the commodity in intermediate and final demands pay the producer price plus the wedge representing the taxed pollution per unit of consumption. Pollution itself is characterized by a vector of 13 measures of various water, air and soil effluents. These include toxic pollutants in water, air and land (TOXAIR, TOXWAT, TOXSOL), bio-accumulative toxic metals in air, soil, and water (BIOAIR, BIOWAT, BIOSOL); air pollutants such as SO_2, NO_2, CO, Volatile organic compounds (VOC), and particulate intensity (PART); and finally, water pollution (biological Oxygen Demand (BOD), and Total Suspended solids (TSS). As mentioned previously, the four critical pollutants for agriculture are toxic chemicals in water and soil, NO_2, and SO_2. We focus and report results on these four pollutants only. The full set of results is available from the authors. We compute the response of agricultural supply to the effluent taxes. these elasticities are small, suggesting that the tax does not induce considerable output effect (positive or negative, since some cleaner sectors can expand at the expense of dirtier sectors) and that abatement is achieved via substitution between intermediate inputs and value added. The values of the output elasticities with respect to the effluent taxes do not exceed 0.01 in absolute value.

The Calibration of the TEQUILA model is based on a detailed social accounting matrix for Mexico, with eight labor categories and 20 households (10 urban households and 10 rural ones). The bulk of labor and capital income is distributed to the different households. Households are utility-maximizers and their preferences are consistent with the extended linear expenditure system (ELES). We do not make an attempt to incorporate the desutility of pollution in household preferences, because it is a methodological challenge and a research program in itself (Espinosa and Smith, 1995). The assumptions on household preferences lead to the average income and price elasticities of final demand which are all inelastic for raw and processed agricultural commodities. Average income elasticities are set to 0.363 for raw commodities, and to 0.545 for processed agricultural goods. The inter-household variation is (0.147 to 0.649) for raw commodities, and (0.440 to 0.623) for processed commodities. The average own-prices elasticities are between -0.16 and -0.195 for raw commodities, and between -0.27 and -0.30 for processed goods. the inter-household ranges are (-0.38 to -0.074) for raw commodities, and (-0.347 to -0.22) for processed agriculture. These values are consistent with conventional wisdom on final consumption in developing economies, that is, markets which are price and income inelastic, but without income-inferior commodities (Sadoulet and de Janvry, 1995, Chapter 2).

Trade is modeled assuming goods are differentiated with respect to region of origin and destination. On the import side, we account for the heterogeneity of imports and domestic goods with the CES specification attributed to Armington. Symmetrically, we assume a CET specification for domestic output, in which producers are assumed to differentiate between the domestic and export markets. We assume that Mexico is a small country; world prices for both Mexican imports and exports are held constant. Trade distortions are expressed as ad valorem tariffs and are shown in Table 2 for the 22 agricultural sectors and the fourteen agriculture-processing sectors. As shown by the Table, some agricultural sectors exhibit high ad valorem tariffs. Processing sectors tend to be less protected, but face higher domestic distortions than raw agricultural commodities as shown in Table 2. The tariffication assumption is consistent with the recent tariffication of most trade distortions in Mexico following its GATT membership and participation in the Uruguay Round Agreement. The assumed Armington and CET elasticities are 3 for agricultural products, 2 for manufacturing sectors, and 1.5 for services. These values correspond to the consensus view that raw commodities exhibit high degrees of substitution, which decrease significantly in processing and even further in the service industry (Sadoulet and de Janvry, 1995, Chapter 12).

Table 2
Sectoral intensity of pollution (in metric tons/$ millions)

Sector	TOXAIR	TOXSOL	TOXWAT	BIOAIR	BIOSOL	BIOWAT	SO_2	NO_2	CO	PART	VOC	TSS	BOD
Maize	0.12	0.35	8.55	0.00	0.00	0.00	0.32	0.20	0.24	0.05	0.44	0.00	0.00
Rice	0.24	0.00	10.79	0.00	0.00	0.00	0.48	0.32	0.08	0.08	1.36	0.00	0.00
Wheat	0.54	3.02	10.49	0.00	0.00	0.00	0.55	0.35	1.88	0.10	1.34	0.00	0.00
Beans	0.05	0.00	5.00	0.00	0.00	0.00	0.33	0.19	0.03	0.05	0.16	0.00	0.00
Sorghum	0.57	2.62	11.22	0.00	0.00	0.00	0.77	0.46	1.65	0.13	1.90	0.00	0.00
Barley	0.24	0.00	6.40	0.00	0.00	0.00	0.36	0.24	0.00	0.00	0.60	0.00	0.00
Soybeans	0.37	1.05	3.43	0.00	0.00	0.00	0.47	0.26	0.69	0.05	1.42	0.00	0.00
Oilseeds	0.00	0.00	0.97	0.00	0.00	0.00	0.48	0.32	0.00	0.00	0.00	0.00	0.00
Sesame	0.00	0.00	5.86	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.17	0.00	0.00
Cotton	0.36	0.51	2.78	0.00	0.00	0.00	0.31	0.21	0.36	0.05	1.91	0.00	0.00
Sugar	0.15	0.00	10.92	0.00	0.00	0.00	0.65	0.39	0.07	0.11	0.76	0.00	0.00
Coffee	0.05	0.00	1.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00
Tobacco	0.26	0.00	5.64	0.00	0.00	0.00	2.31	1.28	0.26	0.26	1.28	0.00	0.00
Cocoa	0.37	0.00	8.88	0.00	0.00	0.00	0.56	0.37	0.00	0.00	1.85	0.00	0.00
Sisal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Other crop	0.35	0.19	4.07	0.00	0.00	0.00	1.14	0.70	0.23	0.19	0.63	0.00	0.00
Beef	0.41	2.27	0.76	0.00	0.00	0.00	0.48	0.29	0.05	0.08	0.01	0.00	0.35
Pork	0.39	2.03	0.65	0.00	0.00	0.00	0.34	0.20	0.04	0.06	0.06	0.00	0.31
Other meat	0.42	2.75	0.76	0.00	0.00	0.00	0.08	0.05	0.01	0.01	0.01	0.00	0.42
Poultry	0.25	1.17	0.52	0.00	0.00	0.00	0.36	0.22	0.04	0.06	0.03	0.00	0.18
Honey	0.00	0.00	0.19	0.00	0.00	0.00	0.56	0.37	0.00	0.00	0.00	0.00	0.00
Other agariculture	0.15	0.00	0.07	0.00	0.00	0.00	0.22	0.15	0.00	0.00	0.82	0.00	0.00

The model includes three closure rules on the government budget, saving/investment, and trade balance. The government saving/deficit is set fixed in real terms. Normally, some tax rate is endogenous to achieve this budget balance. If the household direct tax rate is endogenous, this closure rule can generate significant impacts on the distribution of income, but not on the fundamental efficiency, trade and environmental implications of our simulations. The second closure rule is that investment is savings driven. Changes in saving levels—household, government, or foreign—will have a direct impact on the investment level. The final closure rule holds that the trade balance is fixed (in foreign currency terms). The impact of this closure rule is that trade liberalization leads to a real depreciation, as increasing import demand must be matched by rising exports at constant world prices.

4. Policy scenarios

We first define a reference trajectory for the economy based on DRI-Macgraw-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. All policies are held constant in this reference scenario, called the business-as-usual (BAU) scenario. The model gives us reference trajectory for output, absorption, trade, and pollution emissions, for this BAU scenario. This is the base or reference trajectory of the economy for our analysis. The first reform scenario imposes taxes on pollutants, one at the time. Each tax is such that the emissions of the targeted pollutant progressively decrease over time and reach a 25% decrease relative to its level in the BAU results by 2010. We consider the four major pollutants involved with agriculture: toxic chemical releases in soil and water, SO_2, and NO_2. The phasing in of these taxes is set to obtain gradual reductions of 10% in 1995, 15% in 2000, 20% in 2005, and 25% in 2010.

The second scenario considers a gradual unilateral trade liberalization, with a concurrent but modest exogenous improvement of terms of trade, that is, export prices increase to simulate the improvement

Table 3
Tariffs and production taxes for agriculture and food processing sectors

Sector	Tariff	Production tax
Maize	215.00%	−1.43%
Rice	−48.00%	−1.30%
Wheat	53.90%	−3.09%
Beans	139.00%	−1.10%
Sorghum	24.70%	−2.25%
Barley	47.00%	−1.47%
Soybeans	42.90%	−6.21%
Oil seeds	0.00%	−3.92%
Sesame	0.00%	0.00%
Cotton	10.00%	−1.67%
Sugar	19.00%	−1.13%
Coffee	−54.00%	0.19%
Tobacco	0.00%	−1.04%
Cocoa	0.00%	0.00%
Sisal	0.00%	0.00%
Other crops	2.30%	−0.22%
Beef	0.00%	−0.06%
Pork	0.00%	0.08%
Other meat	10.00%	−0.11%
Poultry	10.00%	0.08%
Honey	0.00%	0.00%
Other agriculture	3.90%	−1.21%
Fisheries	24.80%	0.03%
Dairy	17.30%	−0.46%
Proc. fruit	22.20%	3.68%
Wheat milling	20.50%	−0.35%
Corn milling	0.00%	−1.78%
Coffee proc.	22.30%	0.09%
Sweeteners	13.70%	−3.67%
Oilseed proc.	7.70%	−0.90%
Feed proc.	10.70%	−0.89%
Other food	21.40%	−1.79%
Alc. beverage	23.70%	32.03%
Beer	23.70%	22.57%
Other beverage	23.70%	15.36%
Tobacco manuf.	25.00%	93.23%

Source: Unctad and World Bank.

that should result from the integration of NAFTA countries. We decrease the ad-valorem tariff progressively to free trade, from their reference levels (1989) as 90% of original tariffs in 1995, 60% in 2000, 30% in 2005, and no tariff in 2010. [6] Terms-of-trade effects are expressed as an increase in observed export world prices by 2% in 1995, 4% in 2000, 7% in 2005, and 10% in 2010. The assumption on the improvement of the terms of trade allows us to increase the trade shock to the Mexican economy and to see how the environment is affected by an outward-oriented growth strategy. Our objective is to impose a sizable trade shock on the Mexican economy to estimate changes in sectoral composition of production and trade. These changes determine the pollution emitted and induced by the outward trade orientation. For example, we may find evidence of specialization in dirty agricultural production, with an implicit transfer of environmental services to countries buying Mexican agricultural exports. Conversely, if Mexican pollution-intensive agricultural activities contract under world market discipline, we will have evidence of a 'win–win' situation.

The last reform scenario combines the first two reforms scenario. For this last scenario the objective is to investigate the implications for agriculture of coordinated trade and environment policies. Analytical results (Anderson and Blackhurst, 1992 (Chapter 3); Copeland, 1994; Beghin et al., 1997) imply that the coordinated piecemeal approach—gradual changes of two instruments to correct for trade and environmental distortions—leads to welfare improvements. In the context of joint trade and environmental reforms, efficiency gains are obtained because trade distortions are decreased and because environmental degradation can be reduced as well. Again, our intent is to gauge the effect of such combined reform on sectoral allocation, trade, and pollution abatement. Free trade aligns domestic prices to world prices and the incentives to change input mixes to abate pollution in production have been altered, compared to the case of the single environmental reform. Hence, one may expect substantial differences between the abatement occurring under these scenarios.

5. Results

We present the results for the sequence of three reforms: environmental tax reform, trade liberalization, and combined trade and environmental reforms. Table 4 displays the impact of the reforms on aggregate variables (real GDP, total output, exports, and imports). To present the results at the commodity level we use three sets of tables summarizing the

[6] We use the tariff information such as the one shown in Table 2 and not the PSE information of Table 1.

Table 4
Macroeconomic changes (percent change in 2010 from reference simulation)

Simulations	TOXWAT	TOXSOL	SO_2	NO_2	LIB	TOXWAT + LIB	TOXSOL + LIB	SO_2 + LIB	NO_2 + LIB
Real GDP	−0.5	−1.1	−0.3	−0.3	2.2	1.8	1.2	1.9	1.9
Output	−1.4	−2.5	−0.6	−0.6	2.8	1.7	0.5	2.1	2.1
Private consumption	0.0	−0.4	−0.1	−0.1	2.9	2.8	2.4	2.7	2.7
Investment	−1.4	−3.1	−0.6	−0.6	7.3	5.9	4.2	6.5	6.5
Exports	−1.8	−2.3	−1.2	−1.2	20.4	19.4	18.4	19.0	18.9
Imports	−0.7	−0.5	−1.0	−1.0	30.5	30.4	30.2	29.1	29.1
Absorption	−0.3	−1.0	−0.2	−0.2	3.7	3.3	2.7	3.4	−2.4
Real disposable income	0.2	−0.1	−0.1	−0.1	2.9	3.0	2.6	2.8	2.8

impact on commodity output, trade, and pollution abatement, respectively. We use real GDP as an approximate gauge of the efficiency implications of our policy scenarios (Sadoulet and de Janvry, 1995).

6. Environmental taxes

To achieve the 25% reduction in 2010, we estimate the four taxes as US\$4.7 per kilo of toxics in soil, US\$20.2 per kilo of toxics released in water, US\$9.7 per kg of NO_2 and US\$5.9 per kilo of SO_2 (These are 1989 US dollars). These taxes translate in ad valorem wedges on commodity prices of 2% or less for toxics in soil, between 0 and 19% for toxics in water, 1% or less for NO_2 and SO_2. Relatively low effluent intensities in some sectors result into small taxes for these sectors when they are expressed in percent of the output price. As suggested by Table 4, environmental reforms induce little foregone growth. The tax on toxic chemicals released in soil has the most negative effect on growth and total output (−1.1% change in real GDP, and −2.5% in aggregate output). The taxes' impact on total trade is limited as well. Table 5 shows the changes in agricultural output induced by the policy reform scenarios. The first fourth columns show the impact of reducing the four pollutants relevant to agriculture by 25% with respect to their aggregate level in the BAU reference scenario. The reduction of toxic chemicals in water induces the most changes. Production of wheat, sorghum, soybeans and barley, decrease significantly (−11.5%, −20.3%, −12%, and −8.3% respectively); the effluent tax taxes these commodities heavily because they have high effluent intensities. Total agriculture output decreases by 4.61% with the reduction of toxic chemicals in water. The reduction of toxic chemicals in soil induces small changes, except for honey and coffee, which expand by 17.7 and 13.7%, respectively, because their very low intensity in toxic chemicals released in soil increase their profitability relative to more chemical-intensive crops. The other two environmental reforms leave all agricultural outputs virtually unchanged.

As shown in Table 6, the same environmental tax on toxic chemicals released in water has strong trade effects in the sectors which experienced substantial changes in activity level. Since many of these sectors pollute mostly in production, the tax decreases output in these agricultural markets, but does not affect consumption; imports increase with the environmental tax. Pollution alleviation is a strong motive to import commodities which are pollution-intensive in production, but not in final consumption, and which do not enter polluting processes as intermediate consumption. This tendency to use imports to decrease pollution emitted in production of pollution-intensive goods is observed in several studies looking at trade and environment linkages (see for example, Lee and Roland-Holst (1994) on trade between Indonesia and Japan). For other pollution taxes the trade effects are moderate because the output effect of these taxes is moderate (see Table 6 for more details).

Tables 7–10 show the abatement resulting from the different policy reforms for the four pollutants of interest for agriculture (toxic chemicals in water and soil, SO_2, and NO_2). At the commodity level there are two sources of abatement. The activity output can decrease, and/or the use of inputs (factors, intermediate demands) can change towards a less pollution-intensive input mix. The later effect is the counterpart of the technical effect in Copeland and

Table 5
Agricultural output changes (percent change in 2010 from reference simulation)

Simulations	TOXWAT	TOXSOL	SO_2	NO_2	LIB	TOXWAT + LIB	TOXSOL + LIB	SO_2 + LIB	NO_2 + LIB
Maize	−7.1	−1.9	0.0	0.0	−24.2	−35.2	−26.5	−24.1	−24.1
Rice	−4.0	0.0	0.0	0.0	1.9	−0.9	2.6	1.9	1.9
Wheat	−11.5	−4.1	−0.1	−0.1	−6.0	−19.5	−10.7	−6.1	−6.1
Beans	−5.0	−1.1	0.0	0.0	−20.4	−26.7	−21.3	−20.3	−20.3
Sorhgum	−20.3	−6.1	−0.1	−0.1	−18.4	−37.6	−24.3	−18.4	−18.4
Barley	−8.5	−1.1	0.1	0.0	−19.0	−28.7	−20.2	−18.9	−19.0
Soya	−12.0	−2.0	0.2	0.1	−47.3	−54.0	−48.2	−47.2	−47.2
Oilseeds	−2.6	−1.8	0.0	−0.1	2.0	0.0	0.4	2.0	1.9
Sesame	−6.0	−1.9	0.0	0.0	1.0	−4.2	−0.7	1.0	1.0
Cotton	−2.4	−7.2	0.2	0.2	0.8	−1.3	−6.1	1.0	1.0
Sugar	−8.3	−2.1	−0.1	−0.1	−1.7	−9.4	−3.6	−1.8	−1.8
Coffee	0.8	13.7	1.3	1.4	14.0	17.2	33.7	16.2	16.3
Tobacco	−2.0	−2.6	−0.2	−0.2	2.7	0.9	0.3	2.5	2.5
Cocoa	−4.3	0.1	0.0	0.0	0.3	−3.4	0.8	0.3	0.3
Sisal	−5.0	−1.8	0.1	0.1	−1.1	−5.2	−2.4	−1.0	−0.9
Other crops	−7.1	−1.3	−0.2	−0.2	1.4	−5.3	0.2	1.1	1.2
Beef	−2.0	−0.7	−0.1	−0.1	0.2	−1.3	−0.4	0.1	0.1
Pork	−1.7	−1.0	−0.1	−0.1	−0.2	−1.5	−1.1	−0.3	−0.3
Other meats	−1.2	−0.9	0.0	0.0	−1.4	−2.2	−2.2	−1.5	−1.4
Poultry	−2.4	−1.3	−0.1	−0.1	1.8	−0.2	0.5	1.6	1.6
Honey	12.6	17.7	0.7	0.8	19.6	45.7	51.9	20.9	21.1
Other agri.	0.9	0.3	−0.8	−0.7	−4.7	−3.3	−4.3	−5.8	−5.7
Total agri.	0.00	−1.2	−0.1	−0.1	−3.5	−8.9	−4.5	−3.6	−3.6
Manufactures	−3.4	−6.6	−1.1	−1.2	3.7	1.0	−2.5	2.4	2.3
Services	0.4	0.2	−0.3	−0.3	2.9	3.4	3.2	2.6	2.6

Table 6
Changes in net agricultural trade balance (in millions of US$ 1995)

Simulations	TOXWAT	TOXSOL	SO_2	NO_2	LIB	TOXWAT + LIB	TOXSOL + LIB	SO_2 + LIB	NO_2 + LIB
Maize	−132	−15	1	1	−5884	−8108	−6158	−5853	−5850
Rice	−35	−6	0	0	31	26	30	31	31
Wheat	−490	−133	2	2	−744	−1742	−989	−738	−737
Beans	−25	2	1	1	−1065	−1258	−1041	−1057	−1056
Sorhgum	−1580	−316	4	5	−2200	−4293	−2653	−2192	−2189
Barley	−58	−6	1	1	−273	−389	−286	−271	−270
Soya	−195	55	7	10	−1969	−2119	−1886	−1958	−1953
Oilseeds	1	2	0	0	−4	−3	−2	−4	−4
Sesame	0	0	0	0	0	0	0	0	0
Cotton	0	0	0	0	−2	−3	−2	−2	−2
Sugar	0	0	0	0	0	0	0	0	0
Coffee	−3	−2	0	0	49	48	48	49	49
Tobacco	−2	0	0	0	−1	−3	−1	−1	−1
Cocoa	−13	−2	0	0	−3	−15	−6	−3	−3
Sisal	1	1	0	0	−1	1	0	−1	−1
Other crops	−3116	161	−47	−37	1331	−2029	1550	1244	1259
Beef	−331	187	8	11	442	210	671	449	453
Pork	0	0	0	0	0	0	0	0	0
Other meats	10	21	3	3	−152	−133	−121	−147	−147
Poultry	0	0	0	0	0	0	0	0	0
Honey	116	161	6	7	225	467	525	237	239
Other agri.	25	23	−9	−8	−119	−85	−92	−132	−131

Table 7
TOXWAT emission reduction from production changes (percent change in 2010 from reference simulation)

Simulations	TOXWAT	TOXSOL	SO_2	NO_2	LIB	TOXWAT + LIB	TOXSOL + LIB	SO_2 + LIB	NO_2 + LIB
Maize	−17.6	−6.2	−0.2	−0.2	−24.1	−39.5	−28.6	−24.2	−24.2
Rice	−14.0	−4.3	−0.4	−0.4	2.2	−10.8	−1.4	1.8	1.8
Wheat	−21.6	−9.2	−0.6	−0.6	−5.7	−27.4	−14.5	−6.3	−6.3
Beans	−17.0	−6.0	−0.7	−0.7	−20.3	−33.3	−23.9	−20.6	−20.6
Sorhgum	−29.4	−11.4	−0.6	−0.6	−18.0	−42.8	−27.4	−18.5	−18.5
Barley	−13.3	−3.0	0.0	0.0	−18.5	−31.1	−20.7	−18.5	−19.3
Soya	−16.5	−4.3	−0.9	−0.9	−47.0	−55.2	−48.7	−47.4	−47.4
Oilseeds	−9.1	0.0	0.0	0.0	9.1	0.0	0.0	0.0	0.0
Sesame	−10.0	0.0	0.0	0.0	0.0	−10.0	0.0	0.0	0.0
Cotton	−8.5	−9.4	−0.9	−0.9	1.7	−6.8	−7.7	0.9	0.9
Sugar	−19.2	−6.9	−0.4	−0.4	−1.3	−19.3	−7.7	−1.8	−1.8
Coffee	−12.1	8.1	1.2	1.2	14.5	2.3	27.2	16.2	16.8
Tobacco	−9.1	−4.5	−2.3	−2.3	2.3	−6.8	−2.3	0.0	0.0
Cocoa	−18.8	−6.9	−1.0	−1.0	0.0	−16.8	−5.0	0.0	0.0
Sisal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other crops	−17.9	−5.8	−2.5	−2.5	2.3	−15.3	−3.3	−0.9	−0.9
Beef	−9.4	−2.6	−6.1	−6.1	1.2	−7.7	−1.2	−6.1	−6.2
Pork	−8.0	−2.9	−4.4	4.4	0.7	−6.6	−2.2	−4.4	−5.1
Other meats	−5.9	−3.4	−0.8	−0.8	−0.8	−5.0	−4.2	−1.7	−1.7
Poultry	−10.3	−3.1	−6.7	−6.7	3.1	−6.7	0.0	5.2	−5.2
Honey	0.0	0.0	0.0	0.0	0.0	0.0	50.0	0.0	0.0
Other agri.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total agri.	−18.8	−6.6	−1.5	−1.5	−8.3	−25.5	−13.9	−10.0	−10.0
Manufactures	−24.8	−21.6	−6.4	−6.4	1.3	−24.6	−21.7	−6.8	−6.8
Services	−20.7	−5.3	−19.0	−19.2	6.7	−15.0	1.3	−17.2	−17.5

Taylor (1994) at the commodity level. The output effect at the disaggregated commodity level is the sum of the scale and composition effects at the economy level (Copeland and Taylor, 1994). One could recover the composition effect at the commodity level by subtracting the aggregate output changes (in Table 4) from the commodity-output effect. Since the aggregate output effects are small at the economy level, the individual commodity output changes shown in Table 5 approximate the composition effect when the latter is large. By decreasing the output of polluting activities and by increasing the activity level of less-polluting sectors an economy can abate pollution. For example, the reform involving toxic chemicals in water induces considerable changes in agricultural commodity output for a national aggregate output effect of −1.4%. Consistent with this result, the tax wedges under this reform are the largest as well among the four scenarios.

Tables 7–10 present the total abatement by commodity for the four major pollutants (one table per pollutant) and for the four emission taxes (first four columns). By comparing the latter tables with the output changes of Table 5, we can gauge the magnitude of the technical effects, which are respectable for the emissions of toxic chemicals in water and soil, and substantial for SO_2 and NO_2. Recall that the output effects of the taxes on SO_2 and NO_2 were negligible for most agricultural sectors and the bulk of the abatement for these two pollutants is achieved by changing input mixes towards a cleaner environment.

Another interesting finding with policy implication is the strong multiplier effects, of the SO_2 and NO_2 taxes on the abatement of all emissions, and of any toxic chemical tax on all three toxic chemicals emissions. Tables 7–10 reveal that pollutants are complements in the production of most of the agricultural commodities. This finding is in contrast with results from our study of trade and environment

Table 8
TOXSOL emission reduction from production changes (percent change in 2010 from reference simulation)

Simulations	TOXWAT	TOXSOL	SO_2	NO_2	LIB	TOXWAT + LIB	TOXSOL + LIB	SO_2 + LIB	NO_2 + LIB
Maize	−16.9	−6.1	0.0	0.0	−23.6	−39.2	−28.4	−23.6	−23.6
Rice	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wheat	−21.2	−9.1	0.0	0.0	−5.7	−27.1	−14.5	−5.7	−5.7
Beans	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sorhgum	−29.3	−11.4	−0.2	−0.2	−18.0	−42.7	−27.4	−18.0	−18.0
Barley	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Soya	−15.5	−4.2	0.0	0.0	−46.5	−54.9	−47.9	−46.5	−46.5
Oilseeds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sesame	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cotton	−9.1	−9.1	0.0	0.0	0.0	−9.1	−9.1	0.0	0.0
Sugar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coffee	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Tobacco	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cocoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sisal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other crops	−16.2	−5.7	−0.4	−0.4	1.9	−14.0	−3.4	1.5	1.5
Beef	−3.3	−1.4	−0.1	−0.1	0.5	−2.2	−0.8	0.4	0.4
Pork	−3.1	−1.8	0.0	0.0	0.4	−2.2	−1.3	0.2	0.2
Other meats	−4.3	−3.4	−0.2	−0.2	−0.7	−4.3	−3.7	−0.7	−0.7
Poultry	−3.6	−1.9	0.0	0.0	2.4	−0.6	0.4	2.1	2.1
Honey	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other agri.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total agri.	−17.3	−6.3	−6.8	−6.8	−2.3	−19.2	−8.2	−10.8	−10.9
Manufactures	−15.0	−23.7	−2.2	−2.2	0.6	−14.6	−24.2	−2.2	−2.1
Services	−0.7	−8.1	−0.4	−0.3	3.7	3.5	−4.3	3.3	3.3

linkages in Chile, for which several pollutants are found to be substitutes in production (Beghin et al., 1996a).[7] We draw policy implications in the section on the coordinated trade and environment policy scenario for which similar complementarity occurs.

7. Trade liberalization

At the economy-wide level, the trade liberalization scenario increases real GDP by 2.2% and increases trade substantially: a 20.4% increase in exports and a 30.5% increase in imports (see Table 4, column 5). The fifth column of Table 5 presents the agricultural output consequences of the trade liberalization scenario. The international division of labor implied by the scenario induces a substantial decrease in agricultural output especially for staple crops. This result is consistent with several other studies of trade liberalization in Mexico (e.g., American Farm Bureau, 1991; Grennes and Krissoff, 1993; Levy and van Wijnbergen, 1992). Corn, beans, sorghum, barley, and soybeans decrease substantially. Coffee, honey and tobacco to a lesser extent, increase with the opening of the economy. The corresponding net trade changes are summarized in column 5 of Table 6. Exports of corn, and beans decrease. Wheat, horticulture, beef livestock and other livestock, and honey exports increase. In terms of imports, corn and beans imports increase tremen-

[7] Unlike in approaches imposing fixed emission coefficients by unit of output, complementarity or substitutability of pollutants is an empirical question in our modeling approach and not the result of a pre-imposed matrix of fixed multipliers. We use a similar model structure (with effluent coefficient linked to dirty input use) in our analyses of Chile and Mexico, which leads to opposite 'observed' substitution possibilities between effluents in the two countries.

Table 9
SO_2 emission reduction from production changes (percent change in 2010 from reference simulation)

Simulations	TOXWAT	TOXSOL	SO_2	NO_2	LIB	TOXWAT + LIB	TOXSOL + LIB	SO_2 + LIB	NO_2 + LIB
Maize	−22.2	0.0	−22.2	−22.2	0.0	−22.2	0.0	−22.2	−22.2
Rice	−46.3	−11.9	−38.8	−40.3	−1.5	−47.8	−13.4	−44.8	−46.3
Wheat	−36.8	−10.5	−31.6	−31.6	−21.1	−47.4	−26.3	−47.4	−47.4
Beans	−45.6	−11.7	−32.0	−32.0	−17.5	−55.3	−28.2	−46.6	−47.6
Sorghum	−40.0	0.0	−40.0	−40.0	−20.0	−60.0	−20.0	−40.0	−40.0
Barley	−37.5	−8.3	−25.0	−25.0	−54.2	−66.7	−54.2	−62.5	−62.5
Soybeans	−25.0	0.0	−25.0	−25.0	25.0	−25.0	0.0	−25.0	−25.0
Oilseeds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sesame	−44.4	−11.1	−33.3	−33.3	11.1	−33.3	−11.1	−44.4	−44.4
Cotton	−28.3	−5.7	−24.5	−24.5	0.0	−28.3	−3.8	−28.3	−28.3
Sugar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coffee	−23.1	−7.7	−23.1	−23.1	7.7	−23.1	0.0	−23.1	−23.1
Tobacco	−25.0	0.0	−25.0	−25.0	25.0	−25.0	0.0	−25.0	−25.0
Cocoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sisal	−39.4	−8.2	−33.2	−33.6	6.0	−34.5	−2.3	−34.7	−35.1
Other crops	−40.2	−9.0	−36.4	−36.7	4.9	−35.9	−3.8	−38.9	−39.4
Beef	−34.5	−7.3	−32.7	−32.7	1.8	−32.7	−5.5	−34.5	−36.4
Pork	−33.3	−11.1	−33.3	−33.3	0.0	−33.3	−11.1	−33.3	−33.3
Other meat	−39.3	−9.3	−35.5	−36.4	5.6	−34.6	−2.8	−37.4	−38.3
Poultry	−20.0	20.0	−20.0	−20.0	40.0	20.0	60.0	0.0	0.0
Honey	−25.0	0.0	−25.0	−25.0	0.0	−25.0	0.0	−50.0	−50.0
Other agri.	−27.3	−6.3	−25.0	−25.0	1.6	−24.2	−3.1	−27.3	−27.3
Total agri.	−38.9	−8.4	−33.2	−33.6	1.7	−37.1	−6.4	−37.2	−37.7
Manufactures	−24.4	−10.8	−22.7	−22.7	4.9	−20.5	−6.7	−23.5	−23.6
Services	−31.7	−6.9	−29.2	−29.5	8.6	−24.6	1.5	−28.2	−28.6

dously (by 2670 and 1184%, respectively). Imports of wheat sorghum, barley, soybeans, oilseeds cotton tobacco, cocoa, aloe, horticulture, and livestock increase. Finally, rice and coffee imports decrease.

The environmental consequences of trade liberalization constitute a win–win case for agriculture as an aggregate sector as well as for many commodities, which experience a decline with trade liberalization. Column 5 of Tables 7–10 shows that emissions decrease for the contracting sectors following trade liberalization. These environmental improvements originate in output reduction rather than from less-polluting input mixes. Most of the expanding sectors, e.g., rice, horticulture, coffee, and honey, become more pollution intensive (increase in emission larger that the increase in output). A few contracting sectors increase their emissions. For example, the swine sector contracts with trade liberalization, but increase its emissions of NO_2. This result may be due to increased use of cheaper imported feed which result in more NO_2 intensive animal waste.

8. Coordinated trade and environmental policy reform

The magnitude of the four effluent taxes does not change dramatically under the combined scenario. [8] The combined effect of the joint reforms is approximately additive in terms of changes in GDP, total output and trade (see Table 4, columns 6 to 9). Columns 6 to 9 of Table 5 present the combined output effect of the joint reforms on agricultural commodities. For all commodities combined, total

[8] The taxes are as follows: US$4.6 per kilo of toxics in soil, US$18.7 per kilo of toxics in water, US$12.5 per kilo of NO2, and US$7.5 per kilo of SO2. and translate in ad valorem wedges of about the same magnitude as in the first policy scenario.

Table 10
NO_2 emissions from production changes (percent change in 2010 from reference simulation)

Simulations	TOXWAT	TOXSOL	SO_2	NO_2	LIB	TOXWAT + LIB	TOXSOL + LIB	SO_2 + LIB	NO_2 + LIB
Maize	−20.0	0.0	−20.0	−20.0	20.0	−20.0	20.0	−20.0	−20.0
Rice	−46.3	−12.2	−39.0	−39.0	−2.4	−46.3	−14.6	−43.9	−46.3
Wheat	−41.7	−8.3	−33.3	−33.3	−25.0	−50.0	−33.3	−50.0	−50.0
Beans	−44.4	−11.1	−31.7	−31.7	−17.5	−55.6	−27.0	−46.0	−47.6
Sorghum	−33.3	0.0	−33.3	−33.3	0.0	−33.3	−33.3	−33.3	−33.3
Barley	−35.7	0.0	−21.4	−21.4	−50.0	−64.3	−50.0	−64.3	−64.3
Soybeans	−33.3	0.0	−33.3	−33.3	0.0	−33.3	0.0	−33.3	−33.3
Oilseeds	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sesame	−50.0	−16.7	−50.0	−50.0	0.0	−33.3	−16.7	−50.0	−50.0
Cotton	−30.3	−6.1	−24.2	−24.2	0.0	−27.3	−6.1	−27.3	−30.3
Sugar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coffee	−25.0	0.0	−25.0	−25.0	0.0	−25.0	0.0	−25.0	−25.0
Tobacco	−33.3	0.0	−33.3	−33.3	0.0	−33.3	0.0	−33.3	−33.3
Cocoa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sisal	−39.5	−8.3	−33.3	−33.6	6.1	−34.5	−2.2	−34.7	−35.1
Other crops	−40.3	−8.8	−36.3	−36.7	4.9	−35.8	−4.0	−38.9	−39.4
Beef	−33.3	−6.1	−30.3	−30.3	3.0	−30.3	−3.0	−33.3	−33.3
Pork	−20.0	0.0	−20.0	−20.0	20.0	−20.0	0.0	−20.0	−20.0
Other meats	−39.4	−9.1	−36.4	−36.4	4.5	−34.8	−3.0	−37.9	−37.9
Poultry	0.0	33.3	−33.3	−33.3	33.3	33.3	66.7	0.0	0.0
Honey	−33.3	−33.3	−33.3	−33.3	−33.3	−33.3	−33.3	−66.7	−66.7
Other agri.	−26.9	−5.1	−24.4	−24.4	2.6	−24.4	−2.6	−26.9	−26.9
Total agri.	−38.9	−8.2	−33.3	−33.5	1.7	−36.9	−6.4	−37.2	−37.7
Manufactures	−23.7	−10.4	−22.0	−22.2	5.0	−19.6	−6.0	−22.4	−22.8
Services	−31.7	−6.8	−29.3	−29.5	8.7	−24.7	1.6	−28.3	−28.7

agriculture shrinks by 8.9% for the coordinated reform with the tax on TOXWAT, by 4.5% for the reform with the tax on TOXSOL, and by 3.6% for the coordinated reforms with the SO_2 and NO_2 taxes. Both free trade and environmental reforms contribute to the decrease of agricultural output. The combined effect of the two policies on agricultural output is roughly additive in the aggregate, as well as for many individual commodities.

The trade implications of the coordinated reforms are dominated by the effects of trade liberalization as suggested by Table 6. The surge in agricultural imports induced by trade liberalization is only exacerbated for the combined scenarios. The incentives to abate pollution by importing 'dirty' agricultural commodities are stronger under the joint reforms and they explain the large magnitude of some of the imports increases. The effects on export is much smaller and moderate except for the honey sector.

As shown in Tables 7–10, the emission abatements induced by the combined reforms do not follow the additive pattern of output changes shown in Table 5, but exhibit a variety of patterns. For instance, corn output decreases by 35% for the coordinated scenario of a tax on chemicals in water and free trade, which is higher than the sum of the output decreases obtained with the single reforms. However, the abatement of toxic chemicals in water in that sector is lower for the combined scenario (39.5% in column 5) than for the individual reforms (−17.6 in column 1, and −24.1% in column 4, respectively). Total abatement under the combined scenario tend to be lower that the sum of the individual ones for many commodities and several pollutants (e.g., soybeans, sorghum for the four types of emissions).

The combined reforms insure that virtually all emissions decrease in all sectors except for marginal increases in toxic chemicals for coffee and poultry, and for substantial increments in toxic chemicals released by honey production. The latter effect occurs for the coordinated reforms involving effluent taxes on NO_2 and SO_2, and corresponds to surprising substitution possibilities among pollutants (toxic chemicals released in soil, and SO_2-NO_2) in the production of honey. Poultry and horticulture show similar substitution possibilities across pollutants (SO_2 and NO_2 emissions increase for these sectors in the coordinated scenario which taxes toxic chemicals in soil).

Finally, in the coordinated reforms we also identify a multiplier effect of the tax on a given pollutant on abatement of other emissions. Hence, it appears that some strong complementarity relationships exist among pollutants. For instance, $S0_2$ and NO_2 abatement are positively correlated (a tax on either one induce an analogous effect on both). Similar complementarity exists among toxic chemical effluents. At the sectoral level, some heavy polluters such as corn, and soybeans show complementarity among the four pollutants.

These results on multiplier effects caused by the complementarity of effluents allows us to make a qualified statement on targeting possibilities. This positive correlations between toxic chemicals in air and water, and between NO_2 and $S0_2$, would allow to abate significantly without having to implement four effluent taxes. Two instruments would suffice. Nevertheless, policymakers should be aware that unexpected cross-pollutant effects such as in honey production can occur and that policy coverage should at least be extensive enough to cover these groupings of pollutants as complements (toxic chemicals in one group, NO_2 and SO_2 in another). Even in that event the exception of the honey sector remains. Another possibility is to design the policies by sector. Some sectors such as staple crops require only one policy instrument because of the strong indirect abatement obtained with a tax on any of the four effluents. This fact should allow reduction in the number of policy instruments and facilitate implementation as well.

9. Conclusion

We found that total agricultural output moderately contracts with either environmental reforms or free trade. This moderate output effect dissimulates a substantial change in the commodity composition of agriculture as well as the implied pollution abatement resulting from the reforms. We find no evidence of wholesale environmental degradation in agriculture induced by free trade. To the contrary, many sectors are examples of 'win–win', that is, joint efficiency and environmental gains. The few agricultural sectors which expand do so moderately (e.g., horticulture). When emission increases occur they are induced principally by an expansion of the activity more than by increased effluent intensity.

We identified a variety of abatement patterns depending on the agricultural commodity, and the pollutant types. Nevertheless, opportunities to abate by substituting inputs towards a cleaner mix appear substantial, especially for SO_2 and NO_2. In addition, despite this diversity of effects, we were able to derive policy targeting possibilities aiming at decreasing the number of policy instruments to implement. With the exception of the honey sector, the other agricultural sectors exhibit enough complementarity among effluents to achieve some sizable decrease in the number of environmental taxes. The joint trade and environmental reforms combine the best of both world (efficiency gains from free trade and environmental protection from the taxes). This policy recommendation relies on solid analytical foundations. The contraction of agriculture induced by the joint reform tends to overshadow a fundamental result; unlike agriculture, real GDP increases significantly for these combined policy reforms.

We did not consider an important implication of these policy reforms, which is the adjustment costs associated with the large resource reallocation within and out of agriculture. These costs can be significant although there is no consensus on their extent. Using a village social accounting matrix, Taylor (1994) finds evidence of very diversified farm enterprises such that the contraction of staple crops could occur without dramatic consequences. By contrast, Levy and van Wijnbergen (1995) argue that these costs would be very significant. Until Mexican policy reforms fully unfold these conjectures will remain unsettled.

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