Working Paper Series

WORKING PAPER NO. 646

A REGIONAL, ENVIRONMENTAL, COMPUTABLE GENERAL EQUILIBRIUM MODEL OF THE LOS ANGELES BASIN

by

[illegible]

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS

BERKELEY

CALIFORNIA AGRICULTURAL EXPERIMENT STATION

University of California

DEPARTMENT OF AGRICULTURAL AND RESOURCE ECONOMICS
DIVISION OF AGRICULTURE AND NATURAL RESOURCES
UNIVERSITY OF CALIFORNIA AT BERKELEY

WORKING PAPER NO. 646

A REGIONAL, ENVIRONMENTAL, COMPUTABLE GENERAL EQUILIBRIUM MODEL OF THE LOS ANGELES BASIN

by

Sherman Robinson
Shankar Subramanian
Jacqueline Geoghegan

Department of Agricultural and Resource Economics
University of California, Berkeley

California Agricultural Experiment Station
Giannini Foundation of Agricultural Economics
April 1993

A Regional, Environmental, Computable General Equilibrium Model of the Los Angeles Basin

Sherman Robinson
Shankar Subramanian
Jacqueline Geoghegan

Department of Agricultural and Resource Economics
University of California, Berkeley

April 1993

Funding for this project was provided by the California Energy Commission. Any views expressed in this paper are those of the authors and do not necessarily represent the views or policies of the funding institution.

Table of Contents

Abstract

This paper describes a regional, environmental, multisectoral, computable general equilibrium (CGE) model for the Los Angeles basin. The model, which has 17 sectors, is used to investigate the economic impacts and policy implications of instituting a marketable permit system to reduce air pollution in Los Angeles. The model includes three pollutants (nitrogen oxides, sulfur dioxide, and reactive organic gases) which are emitted according to fixed sectoral coefficients. In the current version, the model does not include any abatement technology. The model uses data on production technology and structure of demand for 1982, which is then updated to 1989; and pollution coefficients are based on data on emissions for 1989. We first measure the direct and indirect pollution effects resulting from changes in final demand using input-output analysis. We then use the CGE model to analyze the impact of imposing emission charges for the three pollutants in order to move toward mandated emission targets. We find that total emission charges required to approach the targets are quite large, indicating a large potential market for emission permits. We also find that, in most cases, the three emission targets can be met by charging for only two pollutants — one of the targets is usually not a binding constraint. This last result is sensitive to model specification, particularly that it does not include abatement technology.

Acknowledgments

We would like to thank James Lichter, Nahid Movassagh, and members of a seminar at the World Bank for helpful comments on an earlier draft. Funding for this project was provided by the California Energy Commission. Any views expressed in this paper are those of the authors and do not necessarily represent the views or policies of the Commission.

This paper describes a regional, environmental, computable general equilibrium (CGE) model for the Los Angeles basin in southern California. The model is the first of a family of models designed to investigate the economic impacts and policy implications of instituting the proposed "marketable permit" scheme to reduce air pollution in Los Angeles. In the next section, we discuss the severe air pollution problems in Los Angeles, the existing regulatory framework, and the newly proposed market-based program to bring the area into attainment for federally mandated levels of air quality. In the third section, we briefly survey environmental CGE models and present our model. We then present some illustrative empirical results using both input-output analysis and our CGE model. We conclude by discussing the model's limitations and outlining steps for further research.

I. Air Pollution in Los Angeles

Los Angeles continues to be the most problematic air quality control region in the country. In the 1990 Federal Clean Air Act Amendments, Los Angeles had the dubious distinction of being the only area in the country with the designation of "extreme" for its level of ozone, and the area with the longest time available —20 years— to attain the National Ambient Air Quality Standards (NAAQS) for ozone. These standards were originally set after the 1970 Clean Air Act Amendments, and Los Angeles continues to have difficulty in attaining them. The original response to these standards was to set up a command and control (CAC) strategy, where the technology for pollution abatement was specified by the regulatory agency. This approach did succeed in reducing pollution somewhat, but at great cost, and the standards still were not all met. There has been growing interest in using a market-based approach, which economists have long advocated as a more efficient way to achieve target levels of pollution abatement.[1]

The South Coast Air Quality Management District (SCAQMD) is in the process of designing a market-based system using emissions permits in order to meet air quality standards in an economically efficient manner. This system will regulate the precursors to ozone: nitrogen oxides (NO_x), reactive organic gases (ROG); and sulfur dioxide (SO_x). Ozone is not directly emitted by sources, but rather is created by a chemical reaction among these precursors in the presence of sunlight. The new approach to air pollution reduction in the Los Angeles basin, RECLAIM ("Regional Clean Air Incentives Market"), is being designed to give firms flexibility in attaining the region's air quality goals. Firms can choose to add on controls, reformulate products, and/or acquire emission reduction credits (ERC's) to achieve these goals. Firms willing to reduce their emissions below the level required by the District will earn ERC's, which they can sell to other firms that find it relatively more expensive to reduce emissions internally. Under this system, economists argue that the target level of emissions reduction will be reached at a lower total cost than under command and control regulation.

The firms that are required to be in the new program are those stationary sources that have District permits for ROG, NO_x, and SO_x and also have annual emissions of greater than 2–4 tons per year (depending on sector). For ROG, under the four-ton limit, there are 1,800 facilities emitting 50,200 tons per year, covering 85% of permitted emissions; for NO_x, 660 facilities emitting 8,190 tons per year, covering 95% of permitted emissions; and for SO_x, about 100 facilities, which are mostly refineries, electric utilities, and chemical plants. Each regulated facility will have an initial allocation of emissions and its own rate of reduction, which may be different for each type of pollutant [SCAQMD (May 1992)]. In aggregate, for ROG, the target is a 5% reduction per year from the initial baseline, and the region is

---

[1] There is an extensive literature on marketable permits. For surveys, see Tietenberg (1985) and Hahn and Hester (1989). Montgomery (1972) provides a theoretical treatment.

expected to meet the California Clean Air Act milestones of 1994, 1997, and 2000. For NO_x, the target reduction is 8% per year from the baseline until 2005, meeting state and federal standards by 1995. The federal NAAQS and state standard for ozone are not expected to be met until 2010. The SO_x reduction is targeted at 8.5% per year from 1994 baseline, with compliance by 2005.

II. The LA-CGE Model

Air quality regulations not only affect firms that are directly affected by the regulations, but also affect other, perhaps non-polluting, firms that do business with the regulated industries. Aggregate pollution generation is obviously strongly influenced by changes in the sectoral structure of production, which, in turn, depend on changes in the structure of demand for final and intermediate goods. By including multisectoral market linkages, a CGE model captures both the direct and indirect effects of changes in government policy.

CGE models were first formulated for national economies.[2] A CGE model simulates a market economy where prices and quantities adjust to clear markets for goods and factors of production. It includes consumers, whose decisions determine the demand for final goods, and profit-maximizing producers, whose decisions determine the supply of goods and the demand for intermediate and primary inputs. The government appears explicitly, generating revenue through various taxes, purchasing goods, and saving (or dissaving). The rest of the world is treated as a supplier of imports and a buyer of exports. A CGE model is complete in that it captures all transactions in the "circular flow" of income. It is Walrasian in that it determines only relative prices — the absolute price level is set exogenously.

Our regional CGE model includes the counties of the South Coast Air Quality Management District (SCAQMD, consisting of Los Angeles, Orange, Riverside, and San Bernadino counties). Many

---

[2] Dervis, de Melo, and Robinson (1982) provide a textbook description of CGE models.

CGE models focus on issues of international trade.[3] Our treatment in the LA-CGE model adapts what has become standard treatment to the requirements of a regional model. Locally produced commodities are assumed to be imperfect substitutes for imported commodities, whether imported from the rest of the U.S. or from foreign countries. Similarly, goods produced in LA and exported are distinguished from goods produced and sold in the region. The responsiveness of trade ratios to changes in the ratio of domestic and external prices is determined by sectoral substitution elasticities. Sectors with low elasticities and low trade shares (e.g. the service sector) are relatively sheltered from the external market. The local price for sectors with high trade shares and/or high substitution elasticities will be largely determined by the external price, with exports and/or imports varying to clear the local market.

Our regional LA-CGE model has a number of special features, given that the region is embedded in a national economy. For example, unlike a national model, Los Angeles is assumed not to have its own currency, so its exchange rate in the model is fixed with respect to the U.S. The region's balance of trade is then determined endogenously. On the trade side, we assume high substitution elasticities for the manufacturing sectors, but also specify some imports as completely non-competitive; that is, they are not produced in the LA region.

In the LA-CGE model, factor markets can be specified as linked to the rest of the U.S., with the wage determined exogenously. In this case, the labor market in LA is assumed to clear by means of labor migration into and out of the region. Alternatively, we can assume a given level of employment in the region, with no migration, and solve for the market-clearing wage. In the experiments reported below, we use the model in this full-employment form.

Finally, aggregate investment in a small regional economy is not determined by aggregate savings in that economy. In the LA-CGE model, we specify aggregate investment as determined exogenously, with capital flows from the rest of the country balancing savings and investment in the LA region.

---

[3] For a survey of trade issues in CGE models, see Robinson (1989).

Environmental CGE Models

In a seminal article, Leontief (1970) presented a multisector input-output model that incorporated environmental externalities. There was an active literature in the 1970s using input-output models to analyze pollution. This work led to the development of economywide, environmental, CGE models.[4] Some of these models focus on analyzing the impact of the Clean Air Act [*e.g.*, Hollenbeck (1979); Hazilla and Kopp (1990)]. Jorgenson and Wilcoxen (1990a,b) developed a dynamic CGE model of the U.S. to explore the costs to the U.S. economy of environmental regulations.

The LA-CGE model is closest in spirit to a series of economywide models developed by Lars Bergman (1988, 1990, 1991). Bergman started with an energy model and then adapted it to include air pollution. Bergman (1990) estimates the impact on Sweden of achieving an 80% reduction in SO_x and a 30% reduction in NO_x emissions between 1980 and 1993, while keeping CO_2 emissions at their 1988 levels. In his model, he simulates the operation of an emissions permit market. He specifies an initial supply of permits that is equal to the total amount of permitted pollution and then solves for their price in equilibrium, under various assumptions about abatement costs and the tightness of the constraints.

The LA-CGE model includes the three categories of regulated air pollutants: NO_x, SO_x, and ROG. In the "Mark I" model presented here, sectoral emission of each pollutant is specified as proportional to output and there is assumed to be no abatement technology available. That is, there are no substitution possibilities which would allow using less polluting inputs, no process changes possible, and no "end-of-the-pipe" abatement available. The only way to reduce aggregate emissions of any pollutant is to change the sectoral structure of production in the LA region away from pollution-intensive sectors. While this treatment is an extreme simplification, it is useful because the model then provides an upper bound to the estimated sectoral adjustments required to reach target air quality goals.

---

[4] The literature on multisector environmental models is briefly surveyed by Robinson (1990), who formulates a small CGE model based on the Leontief model to explore issues of optimal abatement policy using pollution taxes.

The shift in production structure required to meet pollution abatement targets can be achieved either by changing relative prices and hence production incentives (*e.g.*, using pollution charges) or by imposing direct controls limiting the output of polluting sectors. In this paper, we model the use of pollution charges to simulate the operation of a pollution permit market. Given the assumption of fixed pollution coefficients, a pollutant-specific emissions charge translates into a sector-and-pollutant specific output emission charge. The emission charges are collected by the government, which hands the proceeds back to firms as lump-sum transfers. This transfer mechanism simulates the initial distribution of emission permits.

Given a specified target level for each pollutant, the model solves for the emission charge required to meet the target. Ignoring the question of distribution of the emission charges, this system is equivalent to a marketable permit system. That is, the emission charge needed to reach a target level of pollution will be the same as the price of a permit under the same constraint. The revenue generated will equal the value of the entire market in pollution permits.

Multiple pollution targets complicate the analysis somewhat. Consider an economy producing two commodities and two pollutants. Figure 1 shows the production possibility frontier (PPF) for the two outputs X and Y. The two straight lines, D1 and D2, indicate constraints on the emissions of the two pollutants. Initially, both lines pass through the same point on the production possibility frontier. Reducing the maximum allowed emission of pollutant D2 implies shifting the line D2 to the left to D2', and then finding a point on the PPF that is consistent with the new constraint.

Consider the two possibilities. In the left-hand diagram in Figure 1, the two pollution lines are complementary in that sector Y is intensive in the production of both pollutants. Emission of pollutant D2 can be decreased by moving along the PPF (e.g. in response to an emission charge) while at the same time meeting the constraint for emission of pollutant D1. In the right-hand diagram, this complementarity is absent. Instead, one commodity is intensive in producing one pollutant and the other commodity is

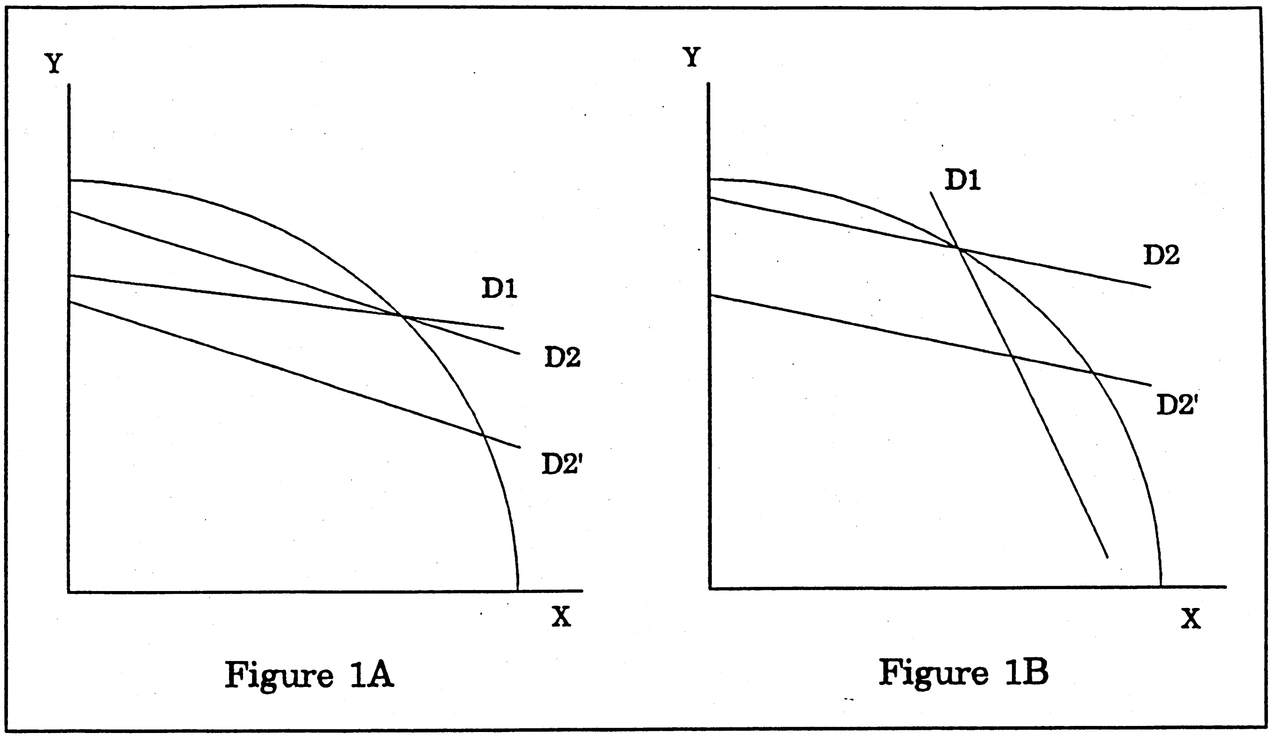


Figure 1: Pollution Constraints and the Production Possibility Frontier

intensive in producing the second pollutant. Now meeting both constraints requires moving the economy to a point inside the PPF, generating unemployment.

In general, with more sectors than pollutants, it may be possible to meet all pollution targets while remaining on the PPF. However, the existence of complementarities and tradeoffs is important. If the pollutants are complementary, it may well be that some of the pollution constraints will be redundant. In this case, pollutants for which the targets are not binding will not require an emissions charge. In the left-hand part of Figure 1, for example, achieving the D2 target implies that the economy more than meets the D1 target. The LA-CGE model allows such a possibility.

Regional Data

The base year for the economic data is 1982, which is the latest year for which the IMPLAN database developed by the US Forest Service provides a SAM and input-output data at the county and state levels. The IMPLAN database contains a 528-sector input-output table, including demand matrices for competitive imports and a vector of total non-competitive imports by use. These were aggregated to 17 sectors (shown in Table 1). The prime consideration in choosing this aggregation was to identify sectors which are major producers of NO_x, SO_x, and ROG.

Data on emissions of these pollutants for 124 industry groups for 1989 were provided by the California Energy Commission. These were also aggregated to conform to the above sectoral specification. We brought the production data to 1989 by multiplying the 1982 flows by the ratio of gross value added in California for 1989 to that for 1982. Even with this adjustment, however, the model mixes production structure and technology data for 1982 with pollution data for 1989, a major shortcoming. Work on updating the 1982 SAM to 1989 is currently under way.

III. Input-Output Analysis

Tables 2 to 4 list the sectors in decreasing order of direct emission coefficients for each pollutant. The "direct" impacts are simply these emission coefficients and are measured in tons of emissions per billions of dollars of output in each sector. The numbers in the table under the "total" heading include these direct impacts plus indirect impacts, taking into account the production linkages throughout the economy. These total "multipliers" incorporate the fact that each sector buys inputs from other sectors that are also polluting and measure the total emissions (in tons) generated per billion dollar increase in final demand of the sectors.[5]

The "total multiplier" numbers measure emissions regardless of where production occurs, assuming that the pollution coefficients are the same for imports as for production in Los Angeles. Under the "domestic" heading are the direct and indirect impacts of production strictly within the LA basin. The domestic I-O table, on which these multipliers is based, excludes the production of goods and services

---

[5] The input-output multiplier model is described in Appendix A.

Table 1:
Sectoral Composition of Emissions and Value Added, and Sectoral Import Shares

		Sectoral composition (percent):				
Sector	Sector name	NOx	ROG	SOx	Value added	Import shares
AGFD	agric and food	1.4 %	0.9 %	1.4 %	2.5 %	53.3 %
MINING	non-oil mining	0.1	0.0	0.0	0.2	64.6
OILGAS	oil and gas extraction	8.5	7.4	6.1	1.2	68.7
LMFG	light manufacturing	3.0	4.8	0.5	3.2	59.5
WOOD	wood & furniture	0.3	11.3	0.0	0.8	45.6
CHEM	chemical products	1.8	6.1	5.7	1.7	69.8
PETR	petroleum products	24.1	12.4	39.8	0.6	13.0
GLASS	glass & cement	9.4	1.1	6.6	0.6	71.4
SVCS	services n.e.c.	5.1	3.7	1.4	53.9	5.8
UTIL	utilities	27.6	3.2	32.2	1.3	29.5
AIRTR	airline transport	10.8	9.1	4.1	0.8	0.0
PDUR	producer durables	5.8	24.5	1.3	11.6	60.9
CDUR	consumer durables	0.5	3.5	0.0	1.4	86.7
TRADE	trade	1.0	4.8	0.6	8.5	40.7
PERS	personal services	0.2	2.7	0.2	0.8	4.7
REPAIR	automobile repair	0.2	4.7	0.1	1.5	0.0
ADMIN	public admin	0.0	0.0	0.0	9.5	0.0
	Sum	100.0 %	100.0 %	100.0 %	100.0	—

Notes:
"Import shares" are the sectoral shares of total supply coming from outside the LA region.

Table 2:
Direct and Indirect Multiplier Coefficients, NOx

Sector	Direct coefficient	Sector	Total multiplier	Sector	Domestic multiplier
GLASS	263.42	UTIL	427.39	UTIL	343.57
UTIL	257.05	GLASS	365.08	GLASS	303.92
OILGAS	158.85	PETR	306.43	AIRTR	218.03
AIRTR	153.44	AIRTR	260.10	PETR	195.98
PETR	124.38	OILGAS	207.59	OILGAS	184.99
MINING	17.33	MINING	102.93	MINING	57.25
CHEM	15.23	CHEM	91.85	CHEM	45.80
LMFG	14.55	LMFG	59.19	LMFG	27.55
PDUR	7.55	AGFD	57.32	AGFD	25.39
AGFD	6.69	CDUR	51.49	PERS	24.50
PERS	6.48	PDUR	51.49	REPAIR	19.61
WOOD	5.36	WOOD	50.61	WOOD	18.31
CDUR	4.20	REPAIR	43.59	TRADE	16.74
REPAIR	2.75	PERS	43.20	SVCS	16.11
TRADE	2.54	TRADE	33.81	CDUR	15.09
SVCS	2.30	SVCS	29.54	PDUR	13.86

Notes:
Direct coefficients are emissions per unit production. Total multipliers are total emissions per unit of change in final demand. Domestic multipliers are total multipliers for LA Region only. Units are tons of pollutant per $ billion of output or final demand.

Table 3:
Direct and Indirect Multiplier Coefficients, ROG

Sector	Direct	Sector	Total	Sector	Domestic
WOOD	269.36	WOOD	357.19	WOOD	290.12
OILGAS	167.20	AIRTR	247.46	AIRTR	207.04
AIRTR	156.86	PETR	244.16	OILGAS	187.95
PERS	99.80	OILGAS	210.48	PETR	135.39
PETR	77.32	UTIL	142.37	PERS	112.38
REPAIR	69.90	CHEM	135.33	CHEM	87.11
CHEM	63.30	PERS	129.81	REPAIR	82.28
PDUR	38.44	REPAIR	111.78	UTIL	64.62
GLASS	36.83	CDUR	102.71	GLASS	55.63
CDUR	35.86	GLASS	92.95	CDUR	47.50
UTIL	35.71	PDUR	92.54	PDUR	45.35
LMFG	28.01	LMFG	78.73	LMFG	39.59
TRADE	14.23	MINING	53.67	TRADE	23.15
AGFD	5.08	AGFD	46.48	MINING	17.95
SVCS	2.00	TRADE	37.57	AGFD	16.07
MINING	1.99	SVCS	26.20	SVCS	12.85

Notes:
Direct coefficients are emissions per unit production. Total multipliers are total emissions per unit of change in final demand. Domestic multipliers are total multipliers for LA Region only. Units are tons of pollutant per $ billion of output or final demand.

Table 4:
Direct and Indirect Multiplier Coefficients, SOx

Sector	Direct	Sector	Total	Sector	Domestic
UTIL	65.12	UTIL	102.20	UTIL	87.38
PETR	44.65	PETR	79.57	PETR	60.46
GLASS	40.28	GLASS	62.01	GLASS	50.04
OILGAS	24.51	AIRTR	37.50	OILGAS	29.91
AIRTR	12.60	OILGAS	33.94	AIRTR	29.14
CHEM	10.65	CHEM	30.10	CHEM	19.04
AGFD	1.43	MINING	21.35	MINING	11.50
PERS	1.40	AGFD	12.50	PERS	6.01
MINING	1.19	CDUR	10.02	AGFD	5.52
LMFG	0.50	WOOD	9.97	REPAIR	4.18
PDUR	0.38	PERS	9.93	TRADE	3.69
TRADE	0.32	LMFG	9.57	LMFG	3.46
REPAIR	0.15	PDUR	9.39	SVCS	3.36
SVCS	0.13	REPAIR	8.92	WOOD	3.02
WOOD	0.06	TRADE	7.33	CDUR	2.33
CDUR	0.05	SVCS	6.06	PDUR	1.68

Notes:
Direct coefficients are emissions per unit production. Total multipliers are total emissions per unit of change in final demand. Domestic multipliers are total multipliers for LA Region only. Units are tons of pollutant per $ billion of output or final demand.

imported into the basin, and also implicitly ignore the emissions released during the production of these imported products. The "domestic" coefficients thus measure the total pollution generated in the LA region per billion dollars increase in final demand for sectoral output.

The total and domestic input-output tables for Los Angeles, and the corresponding multiplier matrices, are given in Appendix A. These multiplier matrices are of interest since their elements show the strength of the production linkages in the economy. For example, reading down the airline transportation column, strong input linkages with the oil and gas, petroleum, and services sectors are evident. As a result, the "total" pollution intensity arising from a change in final demand for airline transportation may be two to ten times larger than its "direct" pollution intensity. However, when comparing the direct to total amounts, the rankings by relative "dirtiness" do not change a great deal. In general, the top five pollution-intensive industries are the same, although the rankings within the top five does change. The influence of both the strength of production linkages and the pollution intensity in each linked sector can be seen by examining the ROG pollution multipliers for the utility sector in Table 3. Considering only the direct impact, this sector is ranked #11, but under the total, which includes the linkages through intermediate flows, this sector is ranked #5. The utility sector use intermediate inputs from highly polluting sectors such as oil and gas and petroleum.

The same type of analysis was performed using only "domestic" data for L.A., *i.e.* excluding all "imports" from outside the LA basin. As a result, one can see the impact of a change in final demand on local production and pollution. Sectors with high import shares should have lower impacts on emissions within the LA region. Import shares in the base year are shown in Table 1. For example, 87% of regional demand for consumer durables is met by imports, while less than 6% of services is imported. In general, when comparing the amounts of total emissions in Table 2 to the amounts of domestic emissions, the same relative rankings hold for the top five most pollution intensive industries. The relative rankings of the less polluting industries change, however, when making this comparison. For example, for NO_x, consumer durables is ranked #10 under total emissions, but since 90% of consumer durables is imported, when looking strictly at domestic production, this sector drops down to #15. This difference is not as marked under ROG, since consumer durables that are produced in LA are not strongly linked to pollution intensive industries.

IV. Empirical Results from the LA-CGE Model

In the first set of experiments with the LA-CGE model, a single emission charge is imposed on each of the three pollutants separately. The model solves for the amounts of emissions of all pollutants and for the total emission charge revenue from taxing the single pollutant. For each pollutant, we ran a series of experiments with increasing pollution charges, terminating with a charge that yields a 25% reduction in the generation of that pollutant. The results are presented in Figure 2. The charges required to achieve a 25% reduction are: \$1.4 million per ton for SO_x, \$470 thousand per ton for NO_x, and \$260 thousand per ton for ROG. Figure 2 also shows the amounts of other pollutants generated under each charging scheme.

The results shown in Figure 2 indicate the outer bound of emission charges required to achieve pollution reduction, given that there is no possibility of abatement. The reduction is achieved solely by changing the structure of demand and production. In a model with abatement, the total cost figures will depend on abatement costs and will be much lower. However, these results can be seen as indicating the cost of achieving additional reductions in pollution generation after abatement possibilities have been exhausted. For example, assume that a costless abatement procedure is discovered which achieves a 25% reduction in SO_x generation. The model indicates that achieving an additional 25% reduction in SO_x through imposition of a SO_x charge would raise almost \$15 billion.

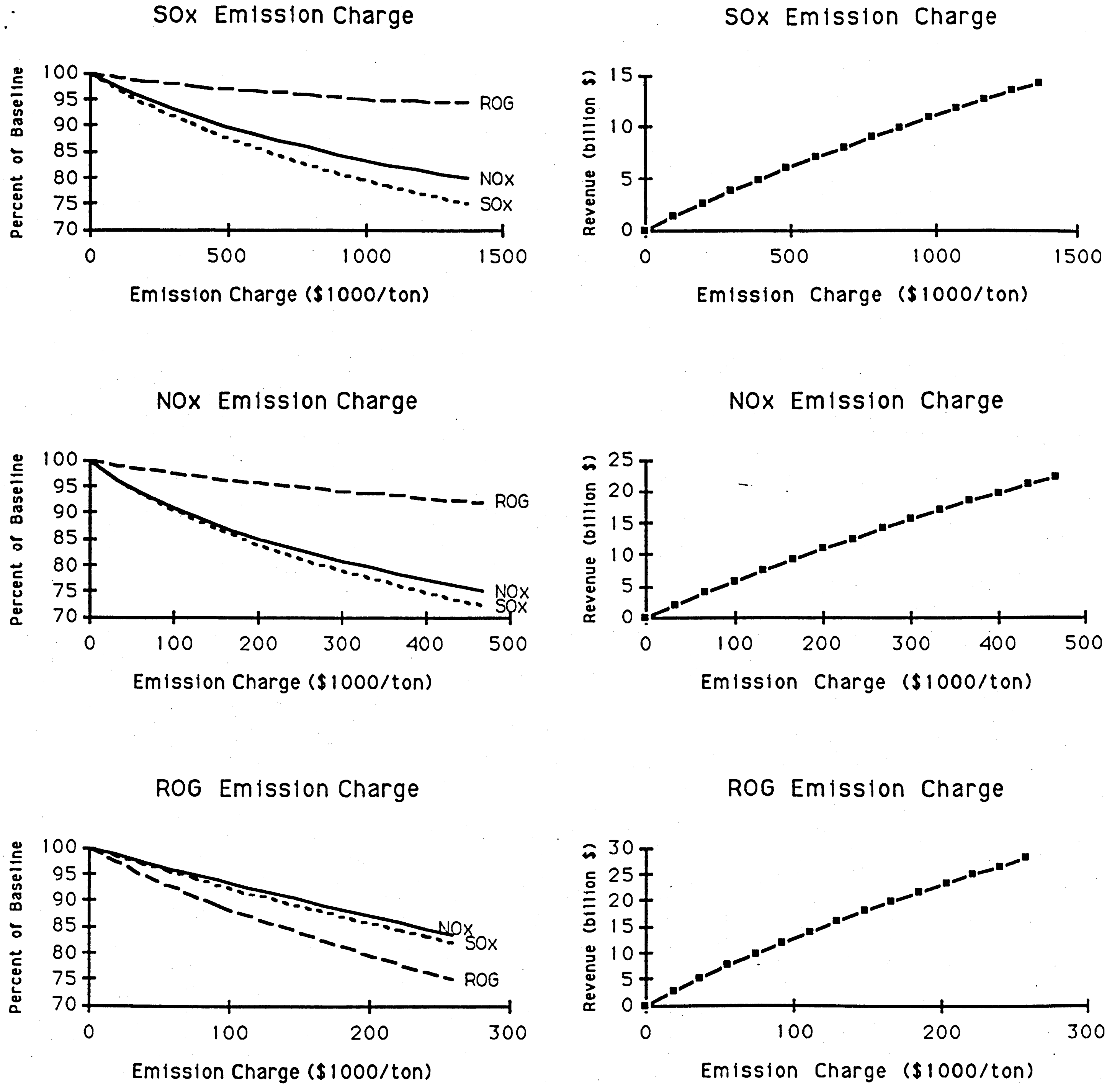

SOx Emission Charge
Percent of Baseline
100
95
90
85
80
75
70
0
500
1000
1500
Emission Charge ($1000/ton)
ROG
NOx
SOx
SOx Emission Charge
Revenue (billion $)
15
10
5
0
0
500
1000
1500
Emission Charge ($1000/ton)
NOx Emission Charge
Percent of Baseline
100
95
90
85
80
75
70
0
100
200
300
400
500
Emission Charge ($1000/ton)
ROG
NOx
SOx
NOx Emission Charge
Revenue (billion $)
25
20
15
10
5
0
0
100
200
300
400
500
Emission Charge ($1000/ton)
ROG Emission Charge
Percent of Baseline
100
95
90
85
80
75
70
0
100
200
300
Emission Charge ($1000/ton)
NOx
SOx
ROG
ROG Emission Charge
Revenue (billion $)
30
25
20
15
10
5
0
0
100
200
300
Emission Charge ($1000/ton)

Figure 2

SO_x and NO_x appear to be complementary in that controlling either yields a very similar structure for emission charge rates, emission reduction, and emission charge revenue generated. The strong complementarity between SO_x and NO_x arises from the fact that the majority of their emissions comes from fossil fuel combustion. The generation of ROG is associated with different sectors and appears to be more difficult to reduce. From Figure 2, a five percent reduction in ROG emissions results in almost $5 billion raised in revenue, while for SO_x, a five percent reduction in emissions raises $2.6 billion in revenues. This difference can be explained by the nature of the ROG-intensive sectors. These include sectors such as personal services, car repair, and airline transportation, which have low trade-substitution elasticities and thus cannot be easily replaced by imports.

In a second set of experiments, we imposed a separate reduction on each emission in order to meet 50% of the final reduction requirements for attainment in 2010. This set of experiments also assumes full employment throughout the Los Angeles region. The impact on a few selected sectors of the economy is shown in Figure 3. Three of these sectors (wood, petroleum, and utilities) were selected because their joint share of emissions is large. The services and consumer durables sectors are of interest because their share in value added is large.

For example, to meet the ROG standard, wood product production would decrease by more than half, but in meeting SO_x and NO_x reduction targets, its output would slightly increase. In the NO_x reduction scenario, the decrease in production in NO_x-intensive sectors releases factors of production which then end up working in other, less NO_x-generating, sectors, such as wood products.

Figure 4 shows the *ad valorem* equivalent indirect tax rates on selected sectors resulting from the emission charges imposed in this set of experiments. The emission charge for each pollutant is the same for every producer, but the equivalent *ad valorem* sectoral tax rates vary because of differing sectoral pollution intensities. The emission charge on ROG, for example, results in a nearly 50% *ad valorem* tax on wood and furniture products, a 20% tax on petroleum refining, and much smaller rates on the other

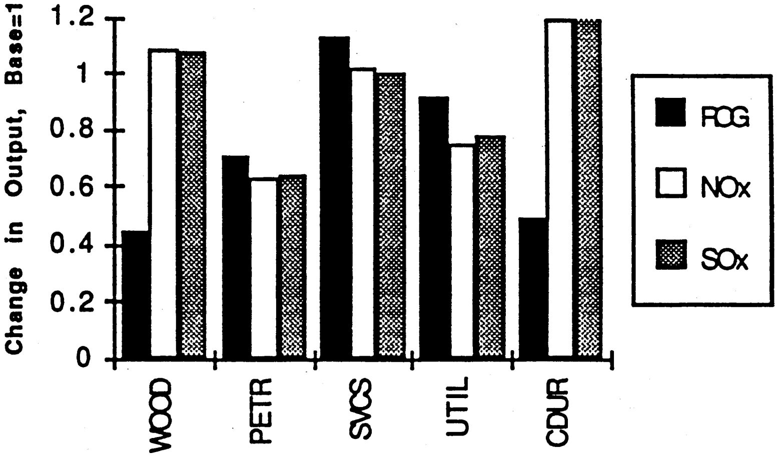


Figure 3

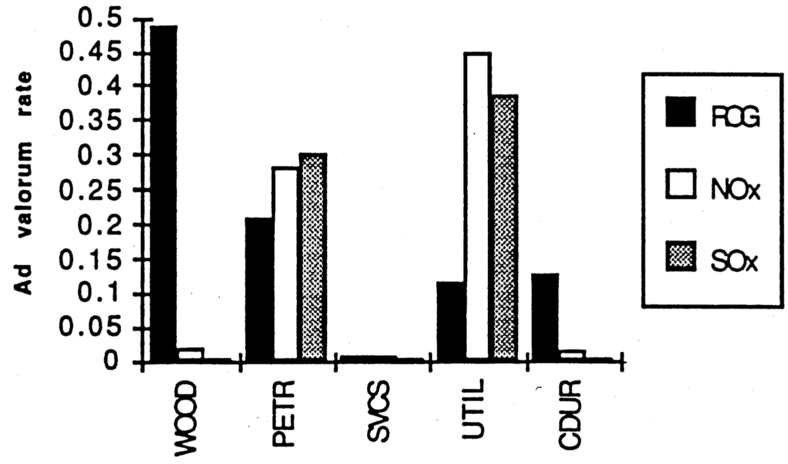


Figure 4

sectors. The NO_x and SO_x emission charges, on the other hand, affect mostly the petroleum and utilities sectors and have little impact on the other sectors.

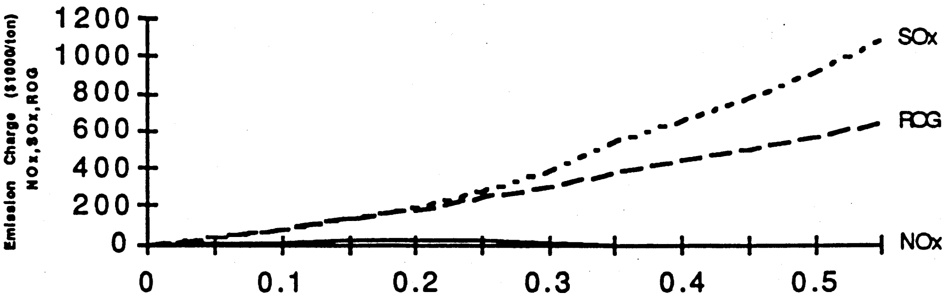
The third set of experiments imposes reductions in total emissions for all three pollutants simultaneously. To illustrate the point made earlier about the possible redundancy of some pollution targets, we move toward these final targets in steps, the intermediate targets being $\Delta + p(1-\Delta)$, where Δ is the final target emission (as a fraction of the base level) and p is varied from 0 (no reduction) to 1 (final target).[6] The final targets are 40% of current emissions for NO_x, 32.5% for SO_x, and 35% for ROG. The required emission charges are shown in Figure 5a. For small values of p (*i.e.* small reductions in emissions), emission charges are needed for all three pollutants because all three constraints are binding. As the reductions increase, the emission charges also go up but that for NO_x soon starts to fall and reaches zero, indicating that the NO_x target becomes redundant. Figures 5b–5c show results for other choices of final reduction targets. In Figure 5b, the final target emissions are the same as for Figure 5a, except that the target for SO_x is higher at 37.5% of the base. In this case, emission charges are needed only for ROG and NO_x; the SO_x target is redundant. In Figure 5c, the final target for SO_x is 30%; now the NO_x constraint does not bind and only ROG and SO_x require emission charges. The reason for this extreme sensitivity of emission charges to the choice of reduction targets is the assumption that in each sector emissions are strictly proportional to output, with no inter-input substitutability and no sector-specific or pollutant-specific abatement technology.

Figure 6 shows the total revenue from the corresponding pollution charge schemes shown in Figure 5. In general, the total revenue from pollution charges needed to achieve the targets is roughly the same in all three scenarios — about $50 billion a year. The charge for ROG is about the same in the three scenarios, while those for SO_x and NO_x vary, depending on which constraint is redundant.

---

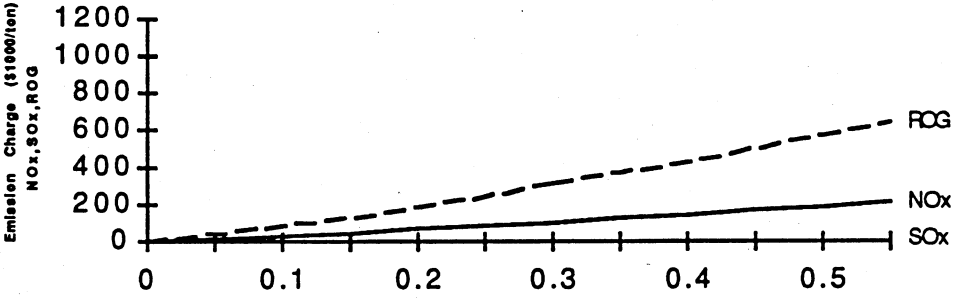
[6] The final targets are similar to those used in the second set of experiments, with the difference that the target for SO_x was changed slightly so that one pollution constraint became redundant as the level of reduction was increased.

Figure 5a



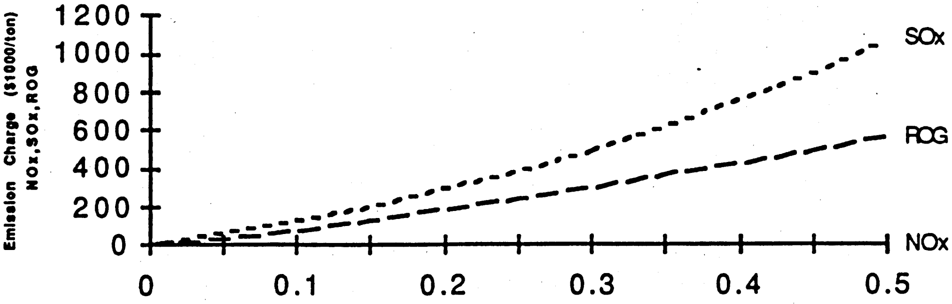
Final Target: 40% NOx, 32.5% SOx, 35% ROG

Figure 5b



Final Target: 40% NOx, 37.5% SOx, 35% ROG

Figure 5c



Final Target: 40% NOx, 30% SOx, 35% ROG

Figure 6a

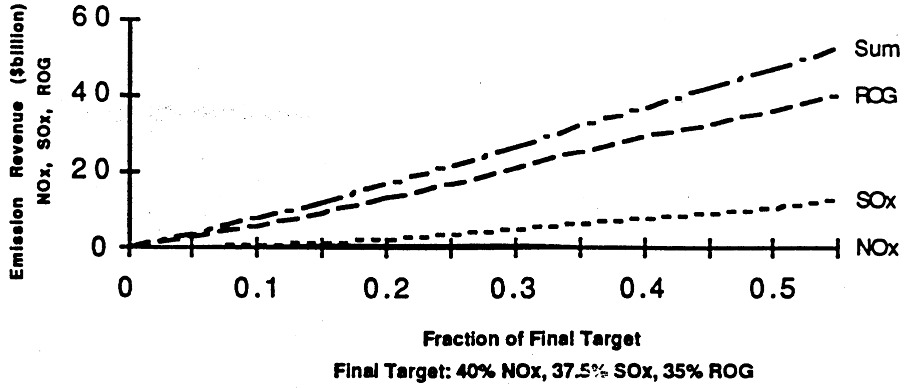


Figure 6b

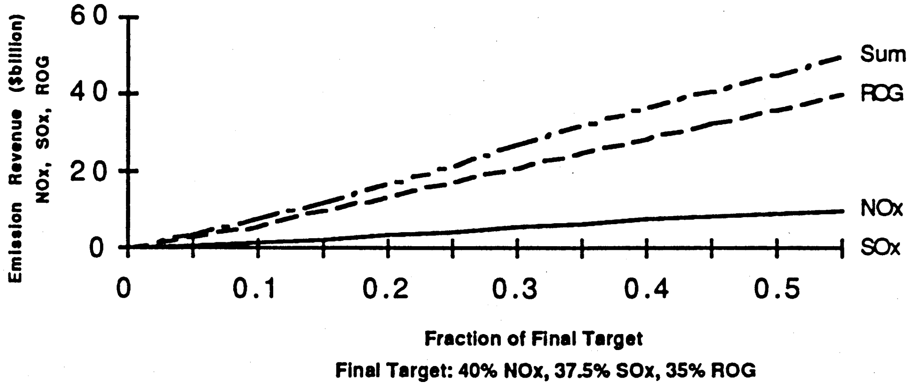
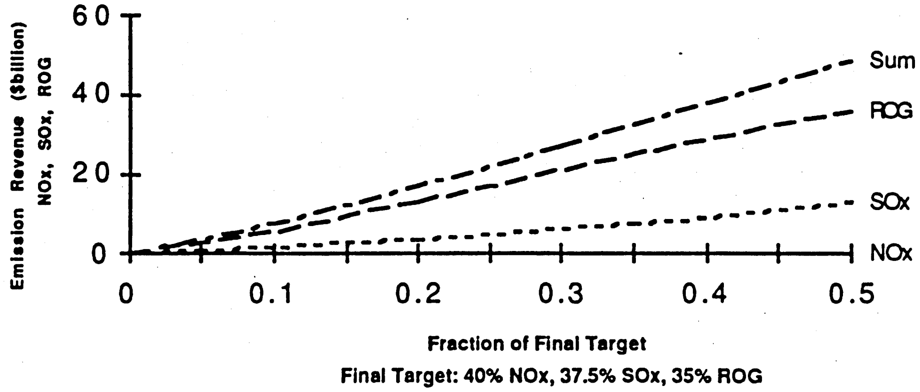


Figure 6c



V. Conclusion

This paper describes an environmental CGE model for the Los Angeles region. In this model, emission charges are used as policy instruments to achieve specified target maximum emission levels. Ignoring distributional effects, a system of emission charges is equivalent to a program of issuing emission permits that can be bought and sold freely. In the model, the emission charge revenue generated for a given level of pollution reduction is equal to the value of the emission permits that correspond to the level of emissions.

The results indicate that pollution generation is highly dependent on the structure of production and that it is feasible to use market-based incentive tools to meet aggregate emission targets. The revenue generated by pollution charges or, equivalently, the value of emission permits is large, around $50 billion, which represents about 6 percent of regional value added. The required adjustment in the structure of production in Los Angeles is also significant. We find that SO_x and NO_x are complementary, appearing together, so that an emission charge on either one leads to a decline in aggregate emissions of both. ROG, on the other hand, originates in different sectors and appears to be harder to control with market-based incentives.

Our initial LA-CGE model makes a number of strong simplifying assumptions, and the empirical results should be seen as providing an upper-bound estimate of both the pollution charges and extent of structural change required to meet emissions targets. The most important simplifications are that there are no abatement possibilities and no possibility of substituting among intermediate inputs with different pollutant generating characteristics. The addition of abatement possibilities will certainly lower the value of total pollution charges required to meet specified targets. However, the model results which indicate the responsiveness of pollution reduction to pollution charges is still relevant, since they indicate the charges required to achieve any additional reductions in pollution after abatement possibilities are exhausted.

Extending the model to include abatement technologies and inter-input substitution possibilities is very important. For example, abatement technologies for NO_x and SO_x evidently differ, so that incorporating such technologies into the model should reduce the high degree of complementarity we found in policies designed to reduce one or the other. Also, there are input-substitution possibilities which can be used to reduce the amount of SO_x produced per unit of energy use, for example, by substituting natural gas for coal.

In addition to extending the model to include abatement and input substitution possibilities, it is also important to distinguish between "old" and "new" firms in each sector. There are policies in place (*e.g.*, "new source review") which differentiate between new and old plants, and it is feasible to capture the distinction in a CGE model.

References

Bergman, Lars (1988). "Energy Policy Modeling: A Survey of General Equilibrium Approaches." Journal of Policy Modeling, 10 (3): 377-399.

Bergman, Lars (1990). "Energy and Environmental Constraints on Growth: A CGE Modeling Approach." Journal of Policy Modeling, 12 (4): 671-691.

Bergman, Lars (1991). "General Equilibrium Effects of Environmental Policy: A CGE Modeling Approach." Environmental and Resource Economics, 1 (1): 43-61.

Dervis, Kemal, Jaime de Melo, and Sherman Robinson (1982). General Equilibrium Models for Development Policy. New York: Cambridge University Press.

Hahn, Robert W., and Gordon L. Hester (1989). "Marketable Permits: Lessons for Theory and Practice." Ecology Law Quarterly, 16 (2): 361-406.

Hazilla, Michael, and Raymond J. Kopp (1990). "Social Cost of Environmental Quality Regulations: A General Equilibrium Analysis." Journal of Political Economy, 98 (4): 853-873.

Hollenbeck, Kevin (1979). "The Employment and Earnings Impacts of the Regulation of Stationary Source Air Pollution." Journal of Environmental Economics and Management, 6: 208-221.

Jorgenson, Dale W., and Peter J. Wilcoxen (1990). "Environmental Regulation and U.S. Economic Growth." RAND Journal of Economics, 21 (2): 314-340.

Jorgenson, Dale W., and Peter J. Wilcoxen (1990). "Intertemporal General Equilibrium modeling of U.S. Environmental Regulation." Journal of Policy Modeling, 12 (4): 715-744.

Leontief, Wassily (1970). "Environmental Repercussions and the Economic Structure: An Input-Output Approach." Review of Economics and Statistics, 52 (2): 262-271.

Montgomery, David W. (1972). "Markets in Licenses and Efficient Pollution Control Programs." Journal of Economic Theory, 5: 395-418.

Robinson, Sherman (1989). "Multisectoral Models." In H.B. Chenery and T.N. Srinivasan, eds., Handbook of Development Economics. Amsterdam: North Holland, 1989.

Robinson, Sherman (1990). "Pollution, Market Failure, and Optimal Policy in an Economywide Framework." Working Paper No. 559, Department of Agricultural and Resource Economics, University of California, Berkeley.

South Coast Air Quality Management District (1992). "Regional Clean Air Incentives Market: Summary Recommendations." Diamond Bar, CA.

Tietenberg, Thomas H. (1985). Emissions Trading. Washington, D.C.: Resources for the Future, Inc.

Appendix A: Input-Output Tables and Multiplier Matrices

Table A1:
Input-Output Table for Los Angeles Basin

$ millions	AGFD	MINING	OILGAS	LMFG	WOOD	CHEM	PETR	GLASS	SVCS	UTIL	PDUR	CDUR	TRADE	PERS	REPAIR	AIRTR
AGFD	4985.0	0.4	0.7	65.0	8.7	100.1	6.0	2.1	824.3	1.0	16.5	4.6	2958.9	0.9	0.3	9.1
MINING	16.3	15.2	4.8	19.8	1.7	136.7	57.5	126.2	159.7	233.6	136.0	5.9	0.2	0.6	0.0	0.0
OILGAS	4.2	1.2	420.4	4.8	1.0	52.6	7311.8	9.8	47.1	1697.4	38.1	1.6	6.2	0.9	2.2	12.1
LMFG	556.2	5.3	6.2	4565.6	209.5	381.6	85.0	85.3	2285.2	15.6	548.2	372.6	643.9	101.3	45.2	47.8
WOOD	11.2	0.6	1.6	74.8	448.0	16.2	4.6	22.6	845.7	3.6	120.4	109.8	9.9	0.6	2.5	0.1
CHEM	349.5	8.6	14.6	554.5	194.9	1520.9	183.1	68.0	1524.1	17.7	1145.7	456.8	135.8	59.5	59.2	6.5
PETR	234.8	25.4	53.7	213.5	40.6	666.5	1546.4	101.9	2278.1	528.3	480.8	58.0	345.2	36.4	135.6	1112.3
GLASS	206.3	0.8	8.0	10.9	32.0	72.6	16.1	204.5	1000.6	0.5	244.0	93.4	29.7	4.6	63.7	0.7
SVCS	1084.8	61.5	478.0	1345.6	376.2	837.0	1096.8	325.8	31452.9	607.9	5180.5	575.1	4034.6	300.0	588.1	783.3
UTIL	197.0	61.4	73.2	183.6	59.9	199.2	418.2	182.8	2015.0	1412.0	924.6	77.4	648.5	78.3	81.5	22.0
PDUR	540.2	46.1	140.5	214.5	365.0	291.3	91.2	92.3	4378.5	57.0	18385.3	1576.4	123.3	15.6	451.9	166.2
CDUR	9.7	3.4	3.6	85.3	8.3	17.3	10.3	9.8	922.1	15.5	331.6	1353.7	50.7	62.6	558.4	4.0
TRADE	863.7	18.5	62.5	767.3	231.8	375.0	227.1	103.7	3873.3	77.8	2912.9	506.8	991.6	58.9	704.3	248.6
PERS	13.1	0.1	0.3	13.7	4.2	6.2	0.7	2.3	108.9	2.1	34.5	4.8	69.0	33.9	8.8	2.0
REPAIR	54.0	6.3	13.8	50.2	22.1	18.2	11.6	12.2	939.0	6.1	146.4	35.9	226.0	18.8	29.4	9.8
AIRTR	45.9	1.8	11.8	111.7	14.9	42.1	26.0	8.0	772.8	8.7	570.7	39.0	99.2	2.6	35.7	319.3
Sum	9172.0	256.4	1293.8	8280.9	2018.9	4733.5	11092.5	1357.3	53427.3	4684.8	31216.1	5271.9	10372.7	775.6	2766.8	2743.7

Table A2:
Total Multiplier Matrix: $(I - A)^{-1}$

	AGFD	MINING	OILGAS	LMFG	WOOD	CHEM	PETR	GLASS	SVCS	UTIL	PDUR	CDUR	TRADE	PERS	REPAIR	AIRTR
AGFD	1.61	0.02	0.01	0.04	0.04	0.05	0.02	0.02	0.02	0.01	0.03	0.03	0.20	0.02	0.04	0.03
MINING	0.01	1.04	0.00	0.01	0.01	0.03	0.01	0.07	0.00	0.05	0.01	0.01	0.00	0.00	0.01	0.01
OILGAS	0.06	0.12	1.18	0.05	0.05	0.14	0.82	0.11	0.04	0.46	0.05	0.05	0.04	0.05	0.05	0.24
LMFG	0.12	0.04	0.02	1.55	0.15	0.12	0.03	0.09	0.04	0.02	0.05	0.13	0.06	0.10	0.05	0.04
WOOD	0.01	0.00	0.00	0.01	1.16	0.01	0.00	0.02	0.01	0.00	0.01	0.03	0.00	0.00	0.01	0.00
CHEM	0.07	0.04	0.02	0.09	0.11	1.28	0.04	0.06	0.03	0.02	0.06	0.13	0.02	0.05	0.04	0.02
PETR	0.06	0.10	0.04	0.06	0.05	0.16	1.18	0.10	0.04	0.14	0.05	0.05	0.04	0.04	0.06	0.33
GLASS	0.03	0.01	0.01	0.01	0.02	0.02	0.01	1.10	0.01	0.00	0.01	0.02	0.01	0.01	0.02	0.01
SVCS	0.27	0.28	0.25	0.29	0.31	0.31	0.34	0.33	1.34	0.28	0.30	0.29	0.28	0.26	0.27	0.38
UTIL	0.06	0.18	0.04	0.05	0.06	0.07	0.09	0.15	0.03	1.29	0.06	0.05	0.05	0.07	0.05	0.04
PDUR	0.14	0.19	0.10	0.08	0.25	0.13	0.10	0.13	0.08	0.08	1.63	0.46	0.05	0.06	0.22	0.11
CDUR	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	1.23	0.01	0.04	0.14	0.01
TRADE	0.14	0.08	0.04	0.12	0.14	0.11	0.06	0.09	0.05	0.05	0.12	0.15	1.07	0.06	0.19	0.10
PERS	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	1.02	0.00	0.00
REPAIR	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	1.01	0.01
AIRTR	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	1.08

Table A3:
Domestic Input-Output Table for LA Basin

$ millions	AGFD	MINING	OILGAS	LMFG	WOOD	CHEM	PETR	GLASS	SVCS	UTIL	PDUR	CDUR	TRADE	PERS	REPAIR	AIRTR
AGFD	2040.3	0.1	0.4	25.5	2.9	51.5	4.3	0.6	493.9	0.5	3.6	2.5	1.5	1477.0	0.3	0.1
MINING	8.9	5.6	3.7	8.6	0.7	78.6	36.7	53.0	99.1	1.1	0.0	9.8	2.6	0.1	0.4	0.0
OILGAS	3.1	0.7	225.6	2.5	0.6	16.9	2506.2	2.7	37.2	164.8	10.2	4.0	0.8	5.5	0.8	2.0
LMFG	416.9	1.6	5.3	986.3	81.6	254.0	77.2	57.2	1503.1	5.6	37.4	136.4	229.4	466.5	59.1	38.1
WOOD	8.2	0.1	0.7	16.2	125.7	10.8	2.2	15.7	411.9	0.4	0.0	26.5	52.6	7.9	0.2	1.0
CHEM	82.4	2.8	9.3	225.7	34.8	600.1	127.4	31.3	328.3	12.5	1.8	98.5	77.7	24.7	40.1	15.9
PETR	199.0	18.6	55.3	179.9	34.4	483.3	1372.2	80.6	2271.6	502.3	977.6	185.6	50.2	322.8	34.4	132.9
GLASS	208.5	0.3	1.2	2.1	10.5	51.3	6.4	48.6	94.2	0.1	0.1	34.2	54.9	15.9	0.2	23.6
SVCS	1103.4	50.3	600.2	1325.8	358.4	832.9	1102.0	304.9	34809.1	622.4	774.3	2273.5	607.1	4208.1	312.7	604.2
UTIL	143.1	37.3	59.6	124.9	39.2	138.1	335.0	133.8	1527.5	1307.0	14.8	275.8	58.2	425.1	54.1	65.6
AIRTR	49.6	1.6	15.6	122.9	15.6	45.7	28.1	8.3	926.4	9.8	332.2	275.4	41.6	109.5	3.0	41.1
PDUR	211.4	8.9	48.5	64.9	78.1	116.1	29.6	35.5	1953.9	34.3	84.5	3651.4	442.3	50.3	4.7	74.3
CDUR	2.7	0.2	1.0	12.9	34.8	4.9	1.1	1.8	147.6	1.6	2.2	39.3	118.0	7.2	5.7	62.7
TRADE	74.9	4.7	37.4	195.7	28.3	82.9	50.6	22.7	2494.1	22.0	165.2	380.4	109.6	272.2	32.0	458.4
PERS	12.8	0.1	0.3	13.4	3.9	5.9	0.7	2.1	115.7	2.1	1.8	14.5	5.0	67.5	34.1	9.0
REPAIR	56.3	5.4	17.2	52.2	21.8	18.7	11.8	11.9	1064.3	6.5	9.6	66.7	36.0	236.1	20.2	32.0
Sum	4621.6	138.1	1081.4	3359.5	871.4	2791.7	5691.6	810.8	48278.1	2693.1	2415.4	7474.8	1887.7	7696.3	602.1	1560.8

Table A4:
Domestic Multiplier Matrix: $(I - A^d)^{-1}$

	AGFD	MINING	OILGAS	LMFG	WOOD	CHEM	PETR	GLASS	SVCS	UTIL	PDUR	CDUR	TRADE	PERS	REPAIR	AIRTR
AGFD	1.18	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.00	0.00	0.07	0.00	0.01
MINING	0.00	1.01	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
OILGAS	0.01	0.02	1.08	0.01	0.01	0.02	0.25	0.02	0.01	0.06	0.06	0.00	0.00	0.01	0.01	0.01
LMFG	0.04	0.01	0.01	1.08	0.03	0.04	0.01	0.03	0.02	0.00	0.02	0.00	0.03	0.03	0.04	0.01
WOOD	0.00	0.00	0.00	0.00	1.04	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
CHEM	0.01	0.01	0.00	0.02	0.01	1.09	0.01	0.02	0.00	0.00	0.01	0.00	0.01	0.00	0.02	0.01
PETR	0.03	0.06	0.03	0.03	0.02	0.09	1.14	0.06	0.03	0.11	0.28	0.01	0.02	0.02	0.03	0.04
GLASS	0.02	0.00	0.00	0.00	0.00	0.01	0.00	1.02	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
SVCS	0.15	0.18	0.27	0.16	0.18	0.20	0.21	0.23	1.35	0.18	0.32	0.08	0.13	0.24	0.24	0.20
UTIL	0.02	0.11	0.03	0.02	0.02	0.03	0.05	0.08	0.02	1.24	0.02	0.01	0.01	0.03	0.04	0.02
AIRTR	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	1.08	0.01	0.01	0.01	0.00	0.01
PDUR	0.02	0.03	0.02	0.01	0.03	0.02	0.01	0.02	0.02	0.01	0.03	1.08	0.06	0.01	0.01	0.02
CDUR	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.02	0.00	0.00	0.01
TRADE	0.01	0.02	0.02	0.02	0.01	0.02	0.01	0.02	0.03	0.01	0.05	0.01	0.02	1.02	0.02	0.10
PERS	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	0.00	1.02	0.00
REPAIR	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.00	0.01	0.01	0.01	1.01

Appendix B: Input-Output Models

This appendix contains a brief description of the input-output methodology for deriving Tables 2–4 in the text. Input-output analysis is a method for studying production linkages in an economy. The analysis starts with an input-output table, which presents the intersectoral flows of intermediate goods in an economy. The columns of the matrix correspond to the *n* different producing sectors, each producing a good or commodity, and to 'consumers' or sources of final demand, such as households, government, changes in inventory, investment, and foreign trade. For each production sector there is a corresponding row and the entries in this row show how much of that commodity is purchased by the production activities as an intermediate input and by each source of final demand. In addition, there are rows for factor payments (or value added) and indirect taxes paid by each production activity.

The value of output in each sector equals the sum of intermediate use, value added, and indirect taxes, which is the same as the sum down the column corresponding to total payments by the sector. Since supply and demand are equal at equilibrium, sectoral output equals total use; *i.e.*, the sum of intermediate and final demands, the row sum for that sector. Should final demand for any commodity change, one would expect changes in the levels of output in every production sector because changes in output levels in any one sector will result in changes in intermediate demands by that sector. The input-output model provides a simple way of determining what change in sectoral outputs will be needed to restore supply-demand equilibrium under certain assumptions. The first assumption is that in every production sector intermediate demand is strictly proportional to output. The second assumption is that every sector has excess capacity so that the desired level of output can be obtained without any increase in unit cost of production.

Input-Output Multipliers

With these assumptions, the input-output model can be formulated in mathematical terms as follows. Let x be the vector of sectoral output and y the vector of final demand. The matrix of input-output coefficients, A, is obtained by dividing each column of the matrix of intermediate demands by the corresponding sectoral output. This matrix is square and has as many rows (and columns) as there are production activities. It is easy to verify that because the matrix A is constructed in this fashion, Ax is the vector of total intermediate demands in the economy. Sectoral output equals the sum of intermediate demand and final demand taken sector by sector. This can be written algebraically as:

$$Ax + y = x.$$

Taking Ax to the right hand side, one obtains:

$$y = x - Ax = (I-A)x.$$

This represents a set of linear equations relating the final demand vector to the sectoral output vector. These equations can be solved by inverting the (I-A) matrix, giving x in terms of y:

$$x = (I-A)^{-1}y.$$

Given the linearity assumptions, a change in final demand (denoted by Δy) will result in a change in sectoral output levels (Δx) given by:

$$\Delta x = (I-A)^{-1}\Delta y.$$

The matrix $(I-A)^{-1}$ is known as the multiplier matrix. The (i,j)th entry denotes the increase in sector i's output resulting from a unit increase in final demand for sector j's product.

These elements therefore show how strong are the production linkages between different sectors.

Pollution

This analysis can be extended to analyze the impact of a change in final demand on pollution levels. In keeping with the linear framework used above, we assume that emission of each pollutant by each production sector is proportional to the level of output in that sector. Let e be the vector of emissions. There are l pollutants so that e is a vector with l elements. We obtain an l by n matrix of pollution coefficients D by dividing each element of e by an element of x. Then e and x are related as follows:

$$e = Dx.$$

Again, because of the linearity we have posited, a change in output Δx gives rise to a change in emissions Δe given by

$$\Delta e = D\Delta x.$$

Combining this with the earlier result gives a relation between a change in final demand Δy and the corresponding change in emissions Δe:

$$\Delta e = D(I-A)^{-1}\Delta y.$$

The (l,j)th element of the matrix D is the increase in emission for pollutant l from sector j resulting from a unit increase in demand for the jth product, while the corresponding element of the matrix $D(I-A)^{-1}$ is the increase in emission for this pollutant in *all* sectors of the economy; *i.e.*, taking into account increases in production resulting from production linkages between sectors. We refer to elements of D as the direct impact and to elements of $D(I-A)^{-1}$ as the total impact coefficients.

The matrix of intermediate demands includes demand both for intermediates produced in the Los Angeles region and those imported into the region. The analysis so far does not exclude imported intermediates and the total impact coefficients therefore include increases in emissions both in the region and elsewhere. This analysis can be repeated using an intermediate use matrix which excludes all imported intermediates. The direct impacts stay the same because the matrix D is unaffected. The total impacts are given by a similar expression, $D(I-A^d)^{-1}$, where A^d is the matrix of domestic input-output coefficients. The domestic total impacts will be smaller because they will necessarily exclude increases in emissions outside the region.

Appendix C: Equations of the LA-CGE Model in the GAMS Language

This appendix presents the equations of the LA–CGE model in the format of the software in which the program was written, GAMS. GAMS stands for "General Algebraic Modeling System" and the software is described in Brooke, Kendrick, and Meeraus (1988).

GAMS statements are case insensitive. Variable and parameter names can use any letters and numbers. We adopt a convention that variable names with a suffix 0 represent base-year values and are specified as parameters (or constants) in the model.

In the GAMS language:

Parameters are treated as constants in the model and are defined in separate "PARAMETER" statements.
"SUM" represents the summation operator, sigma.
"PROD" represents the product operator, pi.
"LOG" is the natural logarithm operator.
"$" introduces a conditional "if" statement.
The suffix .FX indicates a fixed variable.
The suffix .L indicates the level or solution value of a variable.
The suffix .LO indicates the lower bound of a variable.
The suffix .UP indicates the upper bound of a variable.
An asterisk (*) in column one indicates a comment. Some alternative treatments are shown commented out.
A set is defined by a "SET" command.
A subset is denoted by the subset name followed by the name of the larger set in parentheses. In statements, the subset name is then used by itself.
A semicolon (;) terminates a GAMS statement.
Items betweeen slashes ("/") are data.
Relations in equations include: =E= for equal, =L= for less than or equal, and =G= for greater than or equal.

```
*TITLE: Small Los Angeles CGE Model, 1st version, Nov 1992

*################### SET DECLARATION ##############################

SETS

 POL    POLLUTANTS               / nox, rog, sox/

 I      SECTORS                  / agfd       agric and food processing
                                   mining     non-oil mining
                                   oilgas     oil and gas extraction
                                   lmanuf     light manufactures
                                   wood       wood and wood prod furniture
                                   chem       chemical products
                                   petr       petroleum products
                                   glass      glass cement etc (SIC 32)
                                   svcs       services
                                   util       utilities
                                   airtr      airline transp
                                   pdur       prod durables
                                   cdur       consumer durables
                                   trade      trade
                                   pers       personal services
                                   repair     automobile repair
                                   pubadm     public administration/

 F      FACTORS OF PRODUCTION    / labor      labor
                                   capital    capital /

 INS    INSTITUTIONS             / labr       labor
                                   ent        enterprises /

 HH     HOUSEHOLD TYPES          / hhall     all hh/

 IE(I)            EXPORT SECTORS
 IED(I)           SECTORS WITH EXPORT DEMAND EQN
 IEDN(I)          SECTORS WITH NO EXPORT DEMAND EQN
 IEN(I)           NON EXPORT SECTORS

 IM(I)            IMPORT SECTORS
 IMN(I)           NON IMPORT SECTORS

 IP(I)            NOT PUBLIC ADMIN
 ;

 ALIAS(I,J) ;

*######################## PARAMETER DECLARATION #####################

 PARAMETERS

*### READ IN PARAMETERS

*## READ IN FOR INITIALIZATION OF VARIABLES
 ENTTAX0      ENTERPRISE TAX REVENUE
 ENTSAV0      ENTERPRISE SAVINGS
 EXR0         EXCHANGE RATE
 E0(i)        EXPORTS
 FBOR0        NET FOREIGN BORROWING
 FSAV0        NET FOREIGN SAVINGS
 GDTOT0       TOTAL VOLUME OF GOVERNMENT CONSUMPTION
```

```
 GENT0       PAYMENTS FROM GOVERNMENT TO ENTERPRISES
 GOVSAV0     GOVERNMENT SAVINGS
 HHSAV0      HOUSEHOLD SAVINGS
 HHT0        HOUSEHOLD TRANSFERS
 INVEST0     TOTAL INVESTMENT
 M0(i)       IMPORTS
 MPS0(hh)    HOUSEHOLD MARGINAL PROPENSITY TO SAVE
 NCMR(i)     NON-COMPETITIVE IMPORT SHARE
 NCMRH(hh)   NON-COMPETITIVE IMPORT SHARE FOR HOUSEHOLDS
 NCMRG       NON-COMPETITIVE IMPORT SHARE FOR GOVT
 NCMRI       NON-COMPETITIVE IMPORT SHARE FOR INVESTMENT
 PD0(i)      DOMESTIC GOODS PRICE
 PE0(i)      DOMESTIC PRICE OF EXPORTS
 PINDEX0     GNP DEFLATOR
 PM0(i)      DOMESTIC PRICE OF IMPORTS
 PNC0(i)     DOMESTIC PRICE OF NONCOMP IMPORTS
 REMIT0      NET REMITTANCES FROM ABROAD
 SSTAX0      SOCIAL SECURITY TAX REVENUE
 TOTHHTAX0   HOUSEHOLD TAX REVENUE
 XD0(i)      DOMESTIC OUTPUT VOLUME

*## READ IN PARAMETERS AS RATES, SHARES, ELASTICITIES
 DEPR(i)     DEPRECIATION RATES
 DSTR(i)     RATIO OF INVENTORY INVESTMENT TO GROSS OUTPUT
 ESR         ENTERPRISE SAVINGS RATE
 ETR         ENTERPRISE TAX RATE
 GLES(i)     GOVERNMENT CONSUMPTION SHARES
 HTAX(hh)    HOUSEHOLD TAX RATE
 ITAX(i)     INDIRECT TAX RATES
 KISH(i)     SHARES OF INVESTMENT BY SECTOR OF DESTINATION
 RHSH(hh)    HOUSEHOLD REMITTANCE SHARE
 RHOC(i)     ARMINGTON FUNCTION EXPONENT
 RHOE(i)     EXPORT DEMAND PRICE ELASTICITY
 RHOT(i)     CET FUNCTION EXPONENT
 SSTR        SOCIAL SECURITY TAX RATE
 TE(i)       EXPORT SUBSIDY RATES
 TM(i)       TARIFF RATES ON IMPORTS
 THSH(hh)    HOUSEHOLD SHARES OF GOVERNMENT TRANSFERS

*## COMPUTED PARAMETERS FOR INITIALIZATION OF VARIABLES
 DEPRECIA0     TOTAL DEPRECIATION EXPENDITURE
 FD0(f)        FACTOR DEMAND AGGREGATE
 FS0(f)        FACTOR SUPPLY AGGREGATE
 INT0(i)       INTERMEDIATE INPUT DEMAND
 NETSUB0       EXPORT DUTY REVENUE
 P0(i)         PRICE OF COMPOSITE GOOD
 PK0(i)        CAPITAL GOODS PRICE BY SECTOR OF DESTINATION
 PVA0(i)       VALUE ADDED PRICE BY SECTOR
 PWM(i)        WORLD MARKET PRICE OF IMPORTS (IN DOLLARS)
 PWNC(i)       WORLD MARKET PRICE OF NONCOMP IMPORTS
 PWE0(i)       WORLD PRICE OF EXPORTS
 PWSE(i)       WORLD PRICE OF EXPORT SUBSTITUTES
 PX0(i)        AVERAGE OUTPUT PRICE
 VAR0(i)       VALUE ADDED RATE BY SECTOR
 WFDIST0(i,f)  FACTOR PRICE SECTORAL PROPORTIONALITY CONSTANTS
 WF0(f)        FACTOR PRICE AGGREGATE AVERAGE
 XXD0(i)       DOMESTIC SALES VOLUME
 X0(i)         COMPOSITE GOOD SUPPLY VOLUME
 YFCTR0(f)     FACTOR INCOME SUMMED OVER SECTOR
 YFLAND0(i)    FACTOR INCOME FOR LAND AS FRACTION OF CAPITAL INCOME
 YFSECT0(i)    FACTOR INCOME BY SECTOR
 YH0(hh)       HOUSEHOLD INCOME
```

```
 YINST0(ins)   INSTITUTIONAL INCOME

*## COMPUTED PARAMETERS AS RATES, SHARES
 AC(i)         ARMINGTON FUNCTION SHIFT PARAMETER
 AD(i)         PRODUCTION FUNCTION SHIFT PARAMETER
 ALPHA(i,f)    FACTOR SHARE PARAMETER-PRODUCTION FUNCTION
 AT(i)         CET FUNCTION SHIFT PARAMETER
 DELTA(i)      ARMINGTON FUNCTION SHARE PARAMETER
 ECONST(i)     EXPORT DEMAND CONSTANT
 GAMMA(i)      CET FUNCTION SHARE PARAMETER
 PWTS(i)       PRICE INDEX WEIGHTS
 QD(i)         DUMMY VARIABLE FOR COMPUTING AD(i)
 RMD(i)        RATIO OF IMPORTS TO DOMESTIC SALES
 SUMSH         SUM OF SHARE CORRECTION PARAMETER
 SUMHHSH(hh)   SUM OF SHARE FOR HH CLES
 SUMIMSH(i)    SUM OF SHARE FOR IMAT
 TEREAL(i)     REAL EXPORT SUBSIDY RATE IN 1982 DOLLARS
 TMREAL(i)     REAL TARIFF RATE IN 1982 DOLLARS

*## POLLUTION STUFF
 PCOEFF(i,pol) Pollution per unit output
 TPOL0(pol)    Base year total pollution
 TPOL(pol)     Total Pollution Constraint
 DX(i)         OUTPUT REDUCTION FACTOR


 VARIABLES

*#################### VARIABLE DECLARATION ##########################

*## PRICE BLOCK
   EXR       EXCHANGE RATE                           ($ PER WORLD $)
   P(i)      PRICE OF COMPOSITE GOODS
   PD(i)     DOMESTIC PRICES
   PE(i)     DOMESTIC PRICE OF EXPORTS
   PINDEX    GNP DEFLATOR
   PK(i)     PRICE OF CAPITAL GOODS BY SECTOR OF DESTINATION
   PM(i)     DOMESTIC PRICE OF IMPORTS
   PVA(i)    VALUE ADDED PRICE
   PWE(i)    WORLD PRICE OF EXPORTS
   PX(i)     AVERAGE OUTPUT PRICE
*## PRODUCTION BLOCK
   E(i)      EXPORTS                                      (82 BILL $)
   M(i)      IMPORTS                                      (82 BILL $)
   X(i)      COMPOSITE GOODS SUPPLY                       (82 BILL $)
   XD(i)     DOMESTIC OUTPUT                              (82 BILL $)
   XXD(i)    DOMESTIC SALES                               (82 BILL $)
*## FACTOR BLOCK
   FS(f)     FACTOR SUPPLY
   FDSC(i,f) FACTOR DEMAND BY SECTOR
   WF(f)     AVERAGE FACTOR PRICE
   WFDIST(i,f) FACTOR PRICE DIFFERENCES
   YFCTR(f)  FACTOR INCOME                                (BILL $)
*## INCOME AND EXPENDITURE BLOCK
   CD(i)     FINAL DEMAND FOR PRIVATE CONSUMPTION         (82 BILL $)
   DEPRECIA  TOTAL DEPRECIATION EXPENDITURE               (BILL $)
   DK(i)     VOLUME OF INVESTMENT BY SECTOR OF DESTINATION (82 BILL $)
   DST(i)    INVENTORY INVESTMENT BY SECTOR               (82 BILL $)
   ENTSAV    ENTERPRISE SAVINGS                           (BILL $)
   ENTTAX    ENTERPRISE TAX REVENUE                       (BILL $)
   FBOR      NET FOREIGN BORROWING                        (BILL WORLD $)
   FSAV      NET FOREIGN SAVINGS                          (BILL WORLD $)
```

```
   FXDINV    FIXED CAPITAL INVESTMENT                          (BILL $)
   GD(i)     FINAL DEMAND FOR GOVERNMENT CONSUMPTION           (82 BILL $)
   GDTOT     TOTAL VOLUME OF GOVERNMENT CONSUMPTION            (82 BILL $)
   GENT      PAYMENTS FROM GOVT TO ENT                         (BILL $)
   GOVSAV    GOVERNMENT SAVINGS                                (BILL $)
   GR        GOVERNMENT REVENUE                                (BILL $)
   HHSAV     TOTAL HOUSEHOLD SAVINGS                           (BILL $)
   HHT       HOUSEHOLD TRANSFERS                               (BILL $)
   ID(i)     FINAL DEMAND FOR PRODUCTIVE INVESTMENT            (82 BILL $)
   INDTAX    INDIRECT TAX REVENUE                              (BILL $)
   INT(i)    INTERMEDIATES USES                                (82 BILL $)
   INVEST    TOTAL INVESTMENT                                  (BILL $)
   MPS(hh)   MARGINAL PROPENSITY TO SAVE BY HOUSEHOLD TYPE
   NCIMP     NON-COMPETITIVE IMPORTS
   NETSUB    EXPORT DUTY REVENUE                               (BILL $)
   REMIT     NET REMITTANCES FROM ABROAD                     (BILL WORLD $)
   SAVINGS   TOTAL SAVINGS                                     (BILL $)
   SSTAX     SOCIAL SECURITY TAX REVENUE                       (BILL $)
   TARIFF    TARIFF REVENUE                                    (BILL $)
   TOTHHTAX  HOUSEHOLD TAX REVENUE                             (BILL $)
   YH(hh)    HOUSEHOLD INCOME                                  (BILL $)
   YINST(ins) INSTITUTIONAL INCOME                             (BILL $)
*## GDP CALCULATIONS
   GDPVA     VALUE ADDED IN MARKET PRICES GDP                  (BILL $)
   WAL1      WALRAS VARIABLE
   WAL2      WALRAS VARIABLE
   WALOBJ    OBJ FOR WALRAS

*## POLLUTION
   POLLN(i,pol)   POLLUTION LEVEL
   POLLTOT(pol)   Total pollution by type
   PTAX(i)        pollution tax rate by sector
   PTAXP(pol)     pollution tax by pollutant
   PTAXTOT        total pollution taxes
   PHI(i)         FREE VARIABLE FOR OUTPUT REDUCTION
   REDX           uniform output reduction
       ;


 EQUATIONS

*#################### EQUATION DECLARATION ###########################

*## PRICE BLOCK
   PMDEF(i)          DEFINITION OF DOMESTIC IMPORT PRICES
   PEDEF(i)          DEFINITION OF DOMESTIC EXPORT PRICES
   ABSORPTION(i)     VALUE OF DOMESTIC SALES
   SALES(i)          VALUE OF DOMESTIC OUTPUT
   ACTP(i)           DEFINITION OF ACTIVITY PRICES
   PKDEF(i)          DEFINITION OF CAPITAL GOODS PRICE
   PINDEXDEF         DEFINITION OF GENERAL PRICE LEVEL
*## PRODUCTION BLOCK
   ACTIVITY(i)       PRODUCTION FUNCTION
   PROFITMAX(i,f)    FIRST ORDER CONDITIONS FOR PROFIT MAXIMUM
   PROFPUB           FOC FOR PUBADM
   INTEQ(i)          TOTAL INTERMEDIATE USES
   CET(i)            CET FUNCTION
   CET2(i)           DOMESTIC SALES FOR NONTRADED SECTORS
   ESUPPLY(i)        EXPORT SUPPLY
   EDEMAND(i)        EXPORT DEMAND FUNCTIONS
   ARMINGTON(i)      COMPOSITE GOOD AGGREGATION FUNCTION
   ARMINGTON2(i)     COMPOSITE GOOD AGG. FOR NONTRADED SECTORS
```

```
   COSTMIN(i)         F.O.C. FOR COST MINIMIZATION OF COMPOSITE GOOD
   NCEQ               NONCOMPETITIVE IMPORTS
*## INCOME BLOCK
   YFCTREQ(f)         FACTOR INCOME
   LABORY             LABOR INCOME
   ENTY               ENTERPRISE INCOME
   HHY(hh)            HOUSEHOLD INCOME
   TARIFFDEF          TARIFF REVENUE
   INDTAXDEF          INDIRECT TAXES ON DOMESTIC PRODUCTION
   NETSUBDEF          EXPORT SUBSIDIES
   TAXSS              SOCIAL SECURITY TAX
   ETAX               ENTERPRISE TAX
   HHTAXDEF           TOTAL HOUSEHOLD TAXES COLLECTED BY GOVT.
   DEPREQ             DEPRECIATION EXPENDITURE
   ESAVE              ENTERPRISE SAVINGS
   HHSAVEQ            HOUSEHOLD SAVINGS
   GREQ               GOVERNMENT REVENUE
   TOTSAV             TOTAL SAVINGS
*## EXPENDITURE BLOCK
   CDEQ(i)            PRIVATE CONSUMPTION BEHAVIOR
*  GDEQI(i)           GOVT CONSUMPTION OF COMMODITIES
   GDEQ               GOVT CONSUMPTION OF COMMODITIES
   GRUSE              GOVERNMENT SAVINGS
   DSTEQ(i)           INVENTORY INVESTMENT
   FIXEDINV           FIXED INVESTMENT NET OF INVENTORY
   PRODINV(i)         INVESTMENT BY SECTOR OF DESTINATION
   IEQ(i)             INVESTMENT BY SECTOR OF ORIGIN
*## MARKET CLEARING
   EQUIL(i)           GOODS MARKET EQUILIBRIUM
   FMEQUIL(f)         FACTOR MARKET EQUILIBRIUM
   CAEQ               CURRENT ACCOUNT BALANCE (BILL DOLLARS)
   WALRAS             SAVINGS INVESTMENT EQUILIBRIUM
   WOBJ               OBJECTIVE FN
*## GROSS NATIONAL PRODUCT
   GDPY               TOTAL VALUE ADDED INCLUDING INDTAX

*## POLLUTION
   POLLEQ(i,pol)      POLLUTION IN SECTOR i
   polleq2(pol)       Pollution levels by type
   ptaxeq1(i)         pollution tax receipts
   ptaxeq2            total pollution tax
   POLLMAX(pol)       Pollution Constraint
         ;

*######################## EQUATION ASSIGNMENT  #######################

*## PRICE BLOCK

 PMDEF(im)..      PM(im)   =E= PWM(im)*EXR*(1 + TM(im)) ;
 PEDEF(ie)..      PE(ie)   =E= PWE(ie)*(1 + TE(ie))*EXR ;
```

These equations express the relation between the border price of imports (pm) or exports (pe), the the corresponding world prices, tariff rates and the exchange rate. In the Los Angeles model, these tariff rates are all zero and the exchange rate is fixed at 1.

```
 ABSORPTION(i).. P(i)*X(i) =E= PD(i)*XXD(i) +(PM(i)*M(i))$im(i) ;
```

This equation states that the value of domestic absorption (P·X) is the sum of domestic sales (PD·XXD) and imports (PM·M).

```
 SALES(i)..  PX(i)*XD(i) =E= PD(i)*XXD(i) + (PE(i)*E(i))$ie(i) ;
```

Similarly, the value of a firm's output (PX·XD) equals its domestic sales (PD·XXD) plus the value of its exports (PE·E).

```
ACTP(i).. PVA(i) =E= PX(i)*(1.0-ITAX(i)) - SUM(j,IO(j,i)*P(j))
                   - NCMR(i)*PWNC(i)*EXR - PTAX(i) ;
```

The value added per unit (or price of value added, PVA) is the price of the product less indirect taxes (PX(1-ITAX)) less value of inputs used (SUM(j,IO(j,i)*P(j))), less the value of non-competitive imports used in production (NCMR·PWNC·EXR) and the sectoral emission charge (PTAX).

```
PKDEF(i)..       PK(i)    =E= SUM(J, P(j)*IMAT(j,i)) ;
```

This defines the price of capital in each sector as the weighted average of sectoral output prices.

```
PINDEXDEF..      PINDEX =E= SUM(i, pwts(i)*PX(i)) ;
```

This defines the producer price index.

```
*## PRODUCTION BLOCK
```

```
ACTIVITY(i)..    XD(i)    =E= AD(i)*PROD(f$ALPHA(i,f),
                              FDSC(i,f)**ALPHA(i,f)) ;
```

Output is a Cobb-Douglas function of the factor inputs (FDSC, in this case labor and capital).

```
PROFITMAX(ip,f)..  WF(f)*WFDIST(ip,f)*FDSC(ip,f) =E=
    PHI(ip)*XD(ip)*PVA(ip)*ALPHA(ip,f) ;
```

Factor demand equations obtained from profit maximization. The firm's net revenue is PVA·XD, which is why PVA, not P, appears in this equation. It is commonly observed that the same factor may receive different prices in different sectors. The parameter WFDIST allows one to fix these factor price differentials if one so desires.

```
PROFPUB.. WF('labor')*WFDIST('pubadm','labor')
          *FDSC('pubadm','labor')
          =E= XD('pubadm')*PVA('pubadm') ;
```

This equation is only for the public administration sector. This sector hires no capital, hence all payments go to labor.

```
INTEQ(i)..       INT(i)   =E= SUM(J, IO(i,j)*XD(j));
```

Intermediate demand by commodity is the sum of sectoral intermediate demands.

```
CET(ie)..        XD(ie)   =E= AT(ie)*(GAMMA(ie)*E(ie)**RHOT(ie) +
                (1-GAMMA(ie))*XXD(ie)**RHOT(ie))**(1/RHOT(ie)) ;
```

For sectors in which exports and domestic sales are not perfect substitutes. Total production can be divided between domestic sales and exports according to a constant elasticity of transformation (CET) function.

```
CET2(ien)..      XD(ien) =E= XXD(ien) ;
```

In sectors with zero exports, domestic sales and sectoral output are identical.

```
ESUPPLY(ie)..    E(ie) =E= XXD(ie)*(PE(ie)/PD(ie)*(1 - GAMMA(ie))
                              /GAMMA(ie))**(1/(RHOT(ie)-1)) ;
```

In order to maximize total revenue firms divide their production between domestic sales and exports, depending on relative prices in these markets. This equation gives firms' revenue-maximizing export-to-domestic sales ratio.

```
EDEMAND(ied)..   E(ied)   =E= ECONST(ied)*((PWE(ied)/PWSE(ied))
```

```
                                    **(-RHOE(ied))) ;
```

In sectors where the region is not a price taker for its exports, export demand is a downward-sloping function of price.

```
 ARMINGTON(im)..   X(im) =E= AC(im)*(DELTA(im)*M(im)**(-RHOC(im))
      (1-DELTA(im))*XXD(im)**(-RHOC(im)))**(-1/RHOC(im)) ;
```

Imports and the domestic product are not perfect substitutes in consumption. This imperfect substitutability is modeled by assuming that what is consumed is a CES aggregate of the domestic product and the import.

```
 ARMINGTON2(imn)..  X(imn) =E= XXD(imn) ;
```

In sectors with no imports, absorpton equals domestic sales.

```
 COSTMIN(im)..    M(im)/XXD(im) =E= (PD(im)/PM(im)*DELTA(im)/
                                (1 - DELTA(im)))**(1/(1 + RHOC(im))) ;
```

Consumers decide how to allocate their expenditure between the imported and the domestic commodity depending on their relative prices.

```
*## INCOME BLOCK

 YFCTREQ(f)..     YFCTR(f) =E= SUM(i, WF(f)*WFDIST(i,f)*FDSC(i,f))
                + EXR*YFROW0(f);
```

Total income accruing to each factor is the sum over sectors of factor incomes in each sector, to which are added factor incomes accruing from the rest of the world.

```
 LABORY..         YINST("labr") =E= YFCTR("labor") - SSTAX ;
```

The labor institution receives all labor income less social security payments.

```
 ENTY..  YINST("ent")   =E= YFCTR("capital") + GENT
            - (ENTSAV + ENTTAX + DEPRECIA)
           - SUM(ip,(PHI(ip)-1)*XD(ip)*PVA(ip));
```

Enterprise income consists of capital income and government-to-enterprise transfers (GENT), less enterprise savings (ENTSAV), taxes (ENTTAX) and depreciation (DEPRECIA). The last term is used only when one wishes to 'push' firms within the production possibility frontier, thus creating unemployment.

```
 HHY(hh)..        YH(hh) =E= SUM(ins, SINTYH(hh,ins)*YINST(ins))
                             + REMIT*RHSH(hh)*EXR + HHT*THSH(hh) ;
```

Each household group receives its share of institutional income (YINST), remittances (REMIT), and transfers from the government (HHT).

```
 TARIFFDEF..      TARIFF =E= SUM(im, TM(im)*M(im)*PWM(im))*EXR ;
 NETSUBDEF..      NETSUB =E= SUM(ie, TE(ie)*E(ie)*PWE(ie))*EXR ;
```

These equations define total tariffs and export subsidies. These are zero in the current model.

```
 INDTAXDEF.. INDTAX =E= SUM(i, (ITAX(i)*PX(i) + PTAX(i))*XD(i)) ;
```

This equation defines total indirect taxes as the sum of sectoral indirect taxes.

```
 TAXSS..          SSTAX  =E= SSTR*YFCTR("labor") ;
```

Defines social security taxes.

```
 ETAX..     ENTTAX =E= ETR*(YFCTR("CAPITAL") - DEPRECIA + GENT) ;
```

Taxes paid by the enterprise account are the tax rate times capital income less depreciation plus transfers from government.

```
 HHTAXDEF..        TOTHHTAX =E= SUM(hh, HTAX(hh)*YH(hh)) ;
```

Household tax is the household tax rate times household incomes.

```
 DEPREQ..  DEPRECIA =E= SUM(i, DEPR(i)*PK(i)*FDSC(I,"capital")) ;
```

Depreciation is a sector-specific depreciation rate times the value of sectoral capital stocks.

```
 ESAVE.. ENTSAV =E= ESR*(YFCTR("CAPITAL")+GENT-ENTTAX-DEPRECIA);
```

Enterprise savings is a constant savings rate times after-tax enterprise income.

```
 HHSAVEQ..   HHSAV  =E= SUM(hh, MPS(hh)*YH(hh)*(1 - HTAX(hh))) ;
```

Household savings is a fixed fraction of after-tax income.

```
 GREQ..  GR =E= TARIFF - NETSUB + INDTAX +TOTHHTAX
              + SSTAX + ENTTAX + FBOR*EXR ;
```

Government revenues equal total taxes plus foreign borrowings valued in domestic currency. As an accounting convention we assume that all foreign borrowing flows through the government's account.

```
 TOTSAV.. SAVINGS =E= HHSAV + GOVSAV + DEPRECIA
                   + FSAV*EXR + ENTSAV ;
```

Total savings equals the sum of household savings, government savings, depreciation, enterprise savings and foreign savings or the current account deficit.

```
*## EXPENDITURE BLOCK

 CDEQ(i).. P(i)*CD(i)  =E= SUM(hh, CLES(i,hh)*(1-MPS(hh))*YH(hh)
                         *(1-NCMRH(hh))*(1-HTAX(hh))) ;
```

Consumer demand is generated by applying constant budget shares to expenditure on domestic products and competitive imports. Demand for non-competitive imports is a fixed fraction (NCMRH) of total consumption.

```
 GDEQ..            SUM(i,P(i)*GD(i)) =E= (1-NCMRG)*GDTOT ;
```

A fixed fraction (NCMRG) of government expenditure is on non-competitive imports. Expenditure on other items (GD(i)) is specified in real terms.

```
 GRUSE..           GR   =E= GDTOT + GOVSAV + GENT + HHT ;
```

Government savings is government revenues less government consumption (GDTOT) and transfers (HHT, GENT).

```
 DSTEQ(i)..        DST(i) =E= DSTR(i)*XD(i) ;
```

The change in stocks in each sector is a fixed fraction (DSTR) of output.

```
 FIXEDINV.. FXDINV =E= (1-NCMRI)*(INVEST - SUM(i, DST(i)*P(i))) ;
```

`INVEST` is total investment, including inventory accumulation. Total fixed investment is gross investment less inventory accumulation. A fraction NCMRI of this is met by non-competitive imports and the rest is investment demand for the composite commodity.

```
 PRODINV(i)..      PK(i)*DK(i) =E= KISH(i)*FXDINV/(1-NCMRI) ;
```

`KISH(i)` is sector i's share of investment. DK is the resulting change in capital stock.

```
IEQ(i)..          ID(i)   =E= SUM(J, IMAT(i,j)*DK(j));
```

The capital coefficient matrix (IMAT) is used to obtain investment by sector of origin from investment by sector of destination, DK.

```
NCEQ..        NCIMP =E= NCMRG*GDTOT + NCMRI*(INVEST -
                   SUM(i, DST(i)*P(i)))
            +  SUM(hh, (1-MPS(hh))*YH(hh)*NCMRH(hh)*(1-HTAX(hh)))
                     +  SUM(i,EXR*PWNC(i)*NCMR(i)*XD(i));
```

Total non-competitive imports is the sum of non-competitive imports for government consumption, investment, intermediate use and household consumption.

```
*## MARKET CLEARING

EQUIL(i)..  X(i)   =E= INT(i) + CD(i) + GD(i) + ID(i) + DST(i) ;
```

Market equilibrium, supply (X) equals demand.

```
FMEQUIL(f)..      SUM(i, FDSC(i,f)) =E= FS(f) ;
```

Factor market equilibrium: factor supply (FS) equals factor demand added up over sectors.

```
CAEQ..                SUM(im, PWM(im)*M(im)) + NCIMP/EXR
                       =E= SUM(ie, PWE(ie)*E(ie))
                    + SUM(f,YFROW0(f)) + FSAV + REMIT + FBOR + WAL2;
```

Current account balance: competitive imports (PWM·M) plus non-competitive imports (NCIMP) equals exports (PWE·E) plus factor income from the rest of the world, foreign savings, foreign borrowing and remittances. The variable WAL2 is used for checking for imbalances and is fixed at zero.

```
WALRAS..              SAVINGS =E= INVEST + WAL1 ;
```

By Walras' Law savings should equal investment. We put in a slack variable WAL1 and this variable should be zero in the solution if Walras' law is not violated.

```
WOBJ..                WALOBJ =E= WAL1*WAL1 + WAL2*WAL2 ;
```

An alternative objective function, used in model development. If the model is consistent and balanced, WAL1 and WAL2 will be zero in the solution.

```
*## GROSS DOMESTIC PRODUCT

GDPY.. GDPVA =E= SUM(i,PVA(i)*XD(i)) + INDTAX + TARIFF - NETSUB
;
```

Defines value added at market prices.

```
*Pollution equations
PTAXEQ1(i)..      ptax(i) =E= SUM(pol, ptaxp(pol)*pcoeff(i,pol)) ;
```

`Ptaxp(pol)` is the pollution charge per unit of emission. By multiplying this by the pollution coefficient pcoeff(i,pol) and summing over all pollutants one obtains the corresponding tax on sectoral output. The reason is equivalent to applying a pollution charge per unit of emission is that a linear relation is assumed between emission and sectoral output.

```
PTAXEQ2..           ptaxtot =E= SUM(i, ptax(i)*xd(i)) ;
```

Total emission charges equals the sum of sectoral emission charges.

```
 POLLEQ(i,pol)..    POLLN(i,pol) =E= PCOEFF(i,pol)*XD(i) ;
```

Sectoral pollutant emission equals the emission coefficient times sectoral output.

```
 POLLEQ2(pol)..     POLLTOT(pol) =E= SUM(i, POLLN(i,pol)) ;
```

Total emission of a given pollutant equals the sum of sectoral emissions of that pollutant.

```
 POLLMAX(pol)..     POLLTOT(pol) =L= tpol(pol);
```

This places an upper bound on total emissions for each pollutant.

```
*#### ADDITIONAL RESTRICTIONS CORRESPONDING TO EQUATIONS
*# PMDEF, PEDEF, EDEMAND, ESUPPLY, COSTMIN, AND PROFITMAX
*#FOR NON-TRADED SECTORS AND SECTORS WITH FIXED WORLD EXPORT
*#PRICES

 PM.FX(imn)     = PM0(imn) ;
 PE.FX(ien)     = PE0(ien) ;
 PWE.FX(iedn)   = PWE.L(iedn) ;
 E.FX(ien)      = 0;
 M.FX(imn)      = 0;
```

This block fixes exports and imports at zero in sectors where these are zero initially.

```
*################## MODEL CLOSURE ##############################

*## FOREIGN EXCHANGE MARKET CLOSURE
*In this version, the bal. of trade (current acct. bal. FSAV) is
*free and the exchange rate is fixed.

   EXR.FX       = EXR.L ;
*  FSAV.FX      = FSAV.L ;
   REMIT.FX     = REMIT.L ;
   FBOR.FX      = FBOR.L ;

*## INVESTMENT-SAVINGS CLOSURE
```

Investment is fixed and savings adjust, the argument being that investment for a small regional economy is not determined by regional savings.

```
*
* MPS.FX(hh) = MPS.L(hh) ;
  INVEST.FX  = INVEST.L ;
  WAL2.FX =0 ;

*## EXOGENOUS GOVT EXPENDITURE
*## AND GOVT CLOSURE RULE
* Real government spending in each sector is fixed exogenously.
* The government deficit (GOVSAV) is determined residually.
* Transfers are fixed in nominal terms.

*  GDTOT.FX     = GDTOT.L ;
   GD.FX(i)     = GD.L(i) ;
   GENT.FX      = GENT.L ;
```

```
   HHT.FX      = HHT.L ;
*  GOVSAV.FX   = GOVSAV.L ;

*## FACTOR MARKET CLOSURE
* In this version only labor is mobile.
* Commented equations allow a version with fixed wage for labor.
* The model then solves for aggregate employment.

   FS.FX('labor')             = FS.L('labor') ;
   FDSC.FX(i,'capital')       = FDSC.L(i,'capital');
   WF.FX('capital')           = WF.L('capital');
   WFDIST.FX(i,'labor')       = WFDIST0(i,'labor') ;
   WFDIST.FX('pubadm','capital') = 0;
*  WF.FX("labor")             = WF.L("labor") ;
*  FS.LO("labor")             = -inf ;
*  FS.UP("labor")             = +inf ;
```

This version specifies full employment so that labor supply is given exogenously and wages adjust to equate demand and supply of labor. Sectoral capital stocks are fixed and sectoral rates of return are not uniform. A version with complete capital mobility can be obtained by fixing WFDIST(i,'capital'), freeing sectoral capital stocks and fixing aggregate capital stocks.

```
*## NUMERAIRE PRICE INDEX
*In this case, the producer price index

   PINDEX.FX = PINDEX.L ;
```

The price level is fixed at the base year level of 1.00.

```
*######################## END OF MODEL ##########################
```