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Ecological and Economic Impacts within the Environmental Input-Output Framework[1]

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Ecological and Economic Impacts within the Environmental Input-Output Framework

Abstract

The environmental input-output approach reveals the channels through which the environmental burdens of production activities are transmitted throughout the economy. This paper uses the input-output framework and analyses the changes in Spanish emission multipliers during the period 1995-2000. By decomposing the global changes in multipliers into different components, it is possible to evaluate separately the economic and ecological impacts captured by the environmental input-output model. Specifically, in this study we distinguish between the effects on multipliers caused by changes in emission coefficients (the ecological impacts) and the effects on multipliers caused by changes in technical coefficients (the economic impacts). Our results show a significant improvement in the ecological impacts of production activities, which contributed negatively to changes in emission multipliers. They also show a deterioration in the economic impacts, which contributed positively to changes in emission multipliers. Together, these two effects lead to a small reduction in global multipliers during the period of analysis. Our results also show significant differences in the individual behaviour of different sectors in terms of their contribution to multiplier changes. Since there are considerable differences in the way individual sectors affect the changes in emission levels, and in the intensity of these effects, this means that the final effects will basically depend on the activity considered.

Keywords: emission multipliers, multipliers' changes, ecological impacts, economic impacts.

I. INTRODUCTION

The environmental input-output framework integrates the economic and ecological relations that take place within the production system. This approach makes it possible to analyse the amount of pollution generation and the environmental loads of industrial activities in macroeconomic terms. In recent decades, the input-output model has become a useful tool for calculating environmental burdens such as energy consumption, water use, land disturbance and pollution generation, caused by the normal activity of productive sectors.

With regard to pollution generation, several recent contributions have used the input-output model to analyse the patterns that explain the levels of emissions and how these relate to production processes. In this field, Lenzen [10] employed an input-output model to investigate the energy and greenhouse gas flows in the Australian economy. Lenzen et al. [11] constructed a multi-region input-output model, which was used to calculate the CO_2 multipliers for five European countries, taking into account the greenhouse gases embodied in international trade. For applications to Spanish emissions, Alcántara and Roca [1] used the input-output model to analyse the primary energy requirements and CO_2 emissions during the period 1980-1990. More recently, Cadarso and Fernández-Bolaños [3] calculated the total emissions in Spain during the period 1980-1995, by introducing private consumption as another pollutant category. Butnar et al. [2] proposed a different method for analysing Spanish emissions. This paper used a generalized input-output model which determined the key sectors and the input paths of air pollution through the decomposition of global multipliers with structural path analysis, and presented an empirical application for the year 2000.

All these contributions focused on evaluating the levels of emissions and their relations to the levels of production and final demand. Although the environmental input-output approach has mostly been used to study the patterns of global emissions, it can also be used to analyse the factors that influence and modify pollution generation in an economy. Using the input-output model to study not only the pollution levels but also the pollution changes will provide additional knowledge of the environmental relationships that occur within the production system. That is, the intertemporal application of the input-output model allows us to extend the information about the environmental burdens and gas emissions and can help to clarify the transmission channels of pollution throughout the economy.

In the last few decades, the conventional input-output model has developed structural decomposition techniques to analyse the factors that underlie the changes in multipliers. In fact, structural decomposition analysis has become a helpful method for exploring not only the sources of growth in an economy but also the environmental consequences of production activities.[2] In this field, Gowdy and Miller [5] examined the changes in the patterns of energy uses, taking into account both technological and demand changes that took place in the US economy during the period 1963-1977. By isolating both the direct and indirect energy substitutions, Casler and Hannon [4] used the energy input-output model to explore the factors that helped to change the US energy intensities. Han and Lakshmanan [6] analysed the modifications in energy intensities in Japan between 1975 and 1985 by explicitly identifying the effects of energy imports into the input-output model. Kagawa and Inamura [9] proposed a structural decomposition analysis to evaluate the sources of changes in Japanese energy demand between 1985 and 1990.

[2] Rose and Casler [13] provided a detailed review of the structural decomposition literature.

Wier [14] explored Danish gas emissions between 1966 and 1988 by using structural decomposition analysis in which global changes were divided into changes in final demand, input-output coefficients, energy intensities and emissions changes from the household sector.

The aim of this paper is to identify the underlying factors that contribute to modifying the input-output emission multipliers. As the input-output model integrates both the ecological and the economic relations taking place within the production system, a modification in multipliers may be originated for different reasons. In this paper, I evaluate the changes in the ecological and economic relations of production activities separately, which allows one to quantify their individual impacts on the overall multiplier changes. Specifically, I identify two additive components within the global changes in emission multipliers. The first one is based on the ecological burdens of production activities and shows how modifications in the ratio between the level of emissions and the level of sectorial output modify the emission multipliers. The second component is based on the intermediate transactions between sectors and shows how modifications in technical coefficients modify emission multipliers.

The decomposition in this paper can help to explain the generation of pollution and the environmental consequences of the production system. How ecological and economic relations individually affect the gas emission process is valuable information for pollution abatement and pollution control. Naturally, this information can extend our knowledge of the economic-ecological linkages associated with production activities. All of this is useful for defining and implementing successful environmental policies aimed at improving the global efficiency of an economy.

The empirical application is for Spanish emissions and uses both economic and environmental information for 1995 and 2000. The results show that the emission multipliers were smaller in 2000 than in 1995. This reduction is a combination of a significant improvement in the ecological impacts of production activities and a drop in the economic impacts. That is, the global reduction in Spanish emission multipliers is the result of a process characterised by an ecological efficiency and an economic inefficiency within the production system. Also, the changes in emission multipliers are very asymmetric in terms of quantities and depend on factors such as the sector of activity and the type of gas analysed.

The rest of the paper is organised as follows. Section 2 describes the environmental input-output model and presents the decomposition of changes in multipliers into ecological and economic impacts. Section 3 describes the results for the empirical application to Spanish emissions. At the end of the paper, I provide some concluding remarks.

II. CHANGES IN EMISSION MULTIPLIERS AND DECOMPOSITION

The analytical framework that accounts for the changes in pollutant emissions is based on the input-output approach. The standard representation of the input-output model, in matrix notation, can be defined as follows:

$$X = AX + Y = (I - A)^{-1} Y = \alpha Y, \quad (1)$$

where X is the vector of final production in every sector, Y is the vector of final demand, A is a $n \times n$ matrix of technical coefficients (calculated by dividing the industry-by-industry direct requirements of sectorial inputs by the sectorial production), and I is the identity matrix.[3] In expression (1), $(I - A)^{-1} = \alpha$ is the $n \times n$ matrix of input-output multipliers, or the Leontief inverse, and shows the overall effects (direct and indirect) on sectorial production caused by unitary and exogenous increases in the final demand of activities.

The input-output model can be extended to account for the environmental pollution associated with a given level of final production and a given level of final demand. Let B be the $m \times n$ matrix of sectorial emissions per unit of output, in which each element is the amount of gas type k (in physical units) per monetary unit of final production in activity j. The sectorial emissions can then be calculated as follows:[4]

$$F = B(I - A)^{-1} Y = B\,\alpha\,Y = \gamma Y, \tag{2}$$

where F is the vector of total k emissions. The elements in matrix $\gamma = B(I - A)^{-1} = B\alpha$ are the *emission multipliers* and measure the amount of type k emission caused by an exogenous and unitary inflow to the final demand of sector j. Therefore, this approach enables us to identify how the exogenous changes in demand affect the amount of pollutant emissions in the production system.

To study the changes in emission multipliers, we should compare the results corresponding to two different time periods. Specifically, the analysis involves two different matrices of multipliers (γ_1 and γ_0) that we assume have an identical dimension. This means that the two matrices of technical coefficients (A_1 and A_0) and the two

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[3] The input-output model assumes that the input structure of each industry does not vary, so matrix A will remain constant.

[4] Miller and Blair [12] provide a description of this model.

matrices of emissions coefficients (B_1 and B_2) used in the environmental model must reflect an identical disaggregation in the j activities and in the k pollutant gases considered.

If both sides of $\gamma_0 = B_0 (I - A_0)^{-1}$ are post-multiplied by $(I - A_0)$ and the derivative respect to time is taken, it follows that:

$$\Delta\gamma - \gamma_0 \Delta A - \Delta\gamma A_0 - \Delta\gamma \Delta A = \Delta B,$$

$$\Delta\gamma - \gamma_0 \Delta A - \Delta\gamma A_0 - (\gamma_1 - \gamma_0) \Delta A = \Delta B,$$

$$\Delta\gamma \ (I - A_0) = \Delta B + \gamma_1 \Delta A,$$

$$\Delta\gamma = \Delta B \ \alpha_0 + \gamma_1 \Delta A \ \alpha_0. \qquad (3)$$

where $\Delta\gamma$, ΔB and ΔA contain the derivative respect to time of the elements in matrices γ, B and A, respectively. Following expression (3), the changes in emission multipliers ($\Delta\gamma$) have been calculated as the addition of two different components. The first component, $\Delta B \ \alpha_0$, reflects how the changes in emission coefficients modify the emission multipliers, and the second component, $\gamma_1 \Delta A \ \alpha_0$, reflects how the changes in technical coefficients modify the emission multipliers. In expression (3), therefore, the global changes in multipliers have been calculated as the aggregation of two components with different meaning: the *ecological impacts* ($\Delta B \ \alpha_0$) and the *economic impacts* ($\gamma_1 \Delta A \ \alpha_0$).[5]

Following the decomposition in expression (3), we can quantify the effects of changing all the individual coefficients used in the model. This calculation requires the division of

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[5] Note that the economic impacts contain both the changes in direct and indirect effects of activities on the others.

the coefficient matrices by showing all the possible modifications that have taken place. Specifically, the changes in emission coefficients can be analysed separately by writing matrix ΔB as the sum:

$$\Delta B = \Delta B_{11} + \Delta B_{12} + \Delta B_{13} + \ldots + \Delta B_{mn},$$

where each $m \times n$ matrix is made up of the single non-zero entry showing the change in the kjth element: Δb_{kj}. Additionally, the individual effects of technical coefficients can be examined by writing matrix ΔA as the sum:

$$\Delta A = \Delta A_{11} + \Delta A_{12} + \Delta A_{13} + \ldots + \Delta A_{nn},$$

where each $n \times n$ matrix is made up of the single non-zero entry showing the change in the ijth element: Δa_{ij}.

Using the above divisions, we can write expression (3) as follows:

$$\begin{aligned} \Delta\gamma &= \Delta B\ \alpha_0 + \gamma_1\ \Delta A\ \alpha_0 = \\ &= \left(\sum_k \sum_j \Delta B_{kj} \right) \alpha_0 + \gamma_1 \left(\sum_i \sum_j \Delta A_{ij} \right) \alpha_0 = \\ &= \Delta B_{11}\ \alpha_0 + \Delta B_{12}\ \alpha_0 + \ldots + \Delta B_{mn}\ \alpha_0 \\ &\quad + \gamma_1\ \Delta A_{11}\ \alpha_0 + \gamma_1\ \Delta A_{12}\ \alpha_0 + \ldots + \gamma_1\ \Delta A_{nn}\ \alpha_0. \end{aligned} \qquad (4)$$

This expression measures the effects of changing all the coefficients in the model separately and holding changes in all other coefficients constant. Note that expression (4) allows us to evaluate both the ecological and the economic impacts on the multipliers caused by each activity of production. This means that we can individually show the contribution of all the coefficients' modifications on the global changes in emission multipliers.

We can use the above analytical method to divide the changes in emission multipliers into the economic and ecological impacts that take place within the production sphere. This method also shows how the changes in every coefficient in the model affect the global emission multipliers. All this information is extremely useful for defining and implementing successful industrial measures for pollution control and pollution abatement.

III. EMPIRICAL APPLICATION TO SPANISH GAS EMISSIONS

The empirical analysis is for the period between 1995 and 2000, through the use of both economic and environmental data for Spain. The information used comprises the Satellite Atmospheric Emissions Account corresponding to pollution emissions of activities, which are provided by INE [7], and the Supply and the Use tables corresponding to the input-output accounts for the Spanish production system, which are also provided by INE [8]. The information in the Supply and the Use tables are expressed in basic prices.

The Supply and the Use matrices are given in terms of industry by product classification, following respectively the National Classification of Economic Activities (CNAE93) for activities, and the National Classification of Products (CNAP96) for products. These matrices were aggregated for as many as 17 homogeneous activities of production.[6] The matrices A of direct structural coefficients or input-output coefficients

[6] Table 1 shows the activities considered in the empirical application.

are derived from the Use matrices in two steps. First, the elements in the Use matrices are divided by the domestic output of the absorbing industry. Second, the resulting matrices *C* are pre-multiplied by the transposes of the share matrices *D*: $A = D'C$.[7] Matrices *D* are derived from the Supply tables and their elements are calculated by dividing each commodity by the total commodity output.

[PLACE TABLE 1 HERE]

The data on atmospheric emissions are organized in matrices *B*, whose rows contain the amount of pollutants *k* generated by domestic industries *j* (in the columns). The empirical application distinguishes eleven pollutant gases: sulphur oxide (SO_x), nitrogen oxide (NO_x), no methane volatile organic compounds (NMVOC), methane (CH_4), carbon monoxide (CO), carbon dioxide (CO_2), nitrous oxide (N_2O), ammonia (NH_3), sulphur hexafluoride (SF_6), hydro-flour carbonates (HFC) and perfluorocarbonates (PFC).[8] Like the matrices of input-output coefficients, the columns in *B* distinguish 17 activities of production.

The analytical context discussed in section 2 will allow to show how the Spanish emission multipliers have changed during the period of study. Specifically, the calculation of matrix $\Delta\gamma$ and its decomposition will provide useful information about the modifications in both the ecological and the economic channels taking place within the production system. As is logic, this kind of empirical results can help us to understand

[7] Miller and Blair [12] describe these calculations.

[8] Table 1 shows the units of measurement of the gases considered in the analysis.

the underlying factors that contributed to modify the Spanish patterns of pollutant emissions.

The amount of information reported by the model can be organised in different views of the pollution process. First, the total changes in emission multipliers will illustrate how the production system has modified its global environmental burdens. Second, the division of global changes in emission multipliers into ecological and economic impacts will precise which are the reasons of the changes occurred in gas emissions of the Spanish production system.

Global Changes in Emission Multipliers

This section shows the global changes in emission multipliers between the years 1995 and 2000. This perspective of the input-output model allows to identify which production activities have reduced their emissions under new and exogenous shocks in demand and, on the contrary, which production activities have increased it. The information about the environmental improvements or deteriorations in the individual sectors seems to be very valuable for applying abatement measures of industrial pollution.

Table 2 contains the global differences in emission multipliers over the period of analysis. We show in this table the percentage of changes in multipliers, which have been calculated by dividing the changes in individual multipliers by their initial values in 1995: $\frac{\Delta \gamma_{kj}}{\gamma_{kj_{1995}}}$.

[PLACE TABLE 2 HERE]

The elements in table 2 should be read as follows. The element in the first row and the first column indicates that when agriculture (sector 1) receives an exogenous and unitary increase in its final demand, SO_x emissions will reduce by 6.83%. As table 2 shows, there is a great range of variation in the percentages of multipliers' changes, and the final effects will depend on the sector of activity and the type of gas analysed. Private services (sector 16) had the highest positive value, which corresponds to its effects on the HFC emissions (1391.19%). On the contrary, table 2 shows that the most significant reduction was in the SF_6 multiplier of agriculture (sector 1), which is quantified in -81.28%.

Reading table 2 down the columns shows the percentage of changes in the emissions of each pollutant gas when the activity corresponding to the column receives a unitary and exogenous injection in its final demand. The column values reflect, therefore, the changes in all the gas emissions caused by the exogenous inflows to the sector of production in the column. From these multipliers, an interesting result is that only metals (sector 3) show positive changes in the all the column values. Machinery (sector 6) shows multipliers' changes mainly positive, with the exception of its N_2O emissions (-3.53%) and its PFC emissions (-43.39). On the other hand, table 2 has no any column with all negative values, and this indicates that activities increased their emission multipliers at least in one or more pollutant gases during the period of reference.

Reading table 2 across the rows shows the percentage of changes in the emission multipliers of the pollutant gas in the row when there is one unitary injection in the final demand of all the activities simultaneously. The row values reflect, therefore, the changes in the global pollution of every gas caused by the joint inflows to all sectors of production. The global changes in HFC emissions had the greatest global increase (89.18%), and this is consequence of positive changes in the multipliers of this gas by all the activities of production simultaneously. The emissions of SF_6 (18.07%), CO_2 (13.44%) and NO_x (2.84) also show positive changes in the row values, while the other gases in table 2 reduced their emission multipliers during the period of study. Note that this reduction is especially significant in N_2O emissions (-42.09%) and in PFC emissions (-38.52%).

To sum up, table 2 indicates that Spanish emission multipliers have changed in an asymmetric way, given that the impacts of production activities are very heterogeneous. The results show that the final effects essentially depend on the activity that receives the exogenous inflow in final demand. Also from table 2, there are considerable differences in the quantitative changes of the different pollutant gases analysed. This evidence could indicate that industrial abatement measures should have to be individually defined and individually applied to the different activities, mainly if the objective consists in getting uniform reductions in all the gas emissions.

Ecological and Economic Impacts

The analytical method described in section 2 allows to divide the global multiplier changes by isolating the economic and ecological impacts captured within the environmental input-output model. From this decomposition of global multiplier changes, we can identify which is the origin of the modifications in the pollution process. These results may help to understand the channels by which environmental consequences are transmitted throughout the economy, and this may clarify the reasons that cause adjustments in the pollution generation of productive sphere.

The decomposition analysis has been made by individually considering the changes in all the coefficients involved. As the emission coefficients and the technical coefficients take part within the model jointly, the first step has comprised the division of the effects caused by both types of coefficients (following expression (3)). After, the analysis has comprised the introduction of the coefficient changes in every activity of production separately (following expression (4)). This analysis will identify both the economic and the ecological impacts on multipliers caused by changes in the coefficients corresponding to each sector individually. Table 3 summarises the results of the decomposition analysis.

The first two columns in table 3 contain the average of coefficients' changes in every activity. For example, agriculture had an average reduction in its emission coefficients of -1.3768, while in its technical coefficients this reduction was -0.00005.[9] As table 3 shows, there is no general pattern in the modifications of technical coefficients, and some sectors show positive changes and some other show negative ones. In average terms, the differences in coefficients of matrix *A* increased by 0.00331 during the period of analysis. On the other hand, it is interesting that most activities show reductions in their emission coefficients, with the exceptions of metals (0.7120), chemistry (0.1128), paper (0.1598) and finance (0.0030). The average of global reduction in coefficients of matrix *B* was -0.2491, and this means that the Spanish emissions per unit of final production had a general decrease in the period of reference.

[PLACE TABLE 3 HERE]

[9] The sectorial changes in technical coefficients of matrix *A* have been obtained taking into account both the changes in rows and columns of each activity jointly.

The economic effects of multipliers' changes are quantified by an average of 0.41446, and the percentage with respect to the average individual multiplier in 1995 is 11.341%. Therefore, the Spanish emission multipliers show an environmental deterioration because of the modifications in technical coefficients. This deterioration is especially significant when we consider the changes in intermediate coefficients of energy (6.250%) and machinery (4.327%). In fact, these two activities are responsible of the greatest increase in multipliers because of the economic impacts. On the other hand, agriculture, food, textile, paper, commerce and finance had an environmental improvement as a result of the changes in their economic effects (-0.978%, -0.013%, -0.349%, -0.260%, -0.451% and -0.641%, respectively).

The ecological effects contributed negatively to the multipliers' changes, showing that the ecological burdens of production activities were smaller in 2000 than in 1995. Specifically, the reduction in emission multipliers is quantified by an average of -0.68411 and the percentage with respect to the average individual multiplier in 1995 is -18.720%. By sectors of production, energy and agriculture are responsible of the greatest impacts, showing large ecological improvements (-9.256% and -4.587%, respectively). Also from table 3, some activities had ecological deteriorations in terms of the modifications caused in the emission multipliers: metals (1.238%), chemistry (0.444%) and paper (0.575%).

The last two columns in table 3 contain the global effects, which are quantified by -0.26965 and this leads to 7.379% of global reduction. By sectors of production, agriculture and energy had the largest negative contributions (-5.566% and –3.006%, respectively), while machinery and metals had the largest positive ones (2.787% and

2.290%, respectively). These negative changes in multipliers indicate that the levels of emissions in production activities under exogenous and unitary shocks in final demand reduced during the period of analysis. This reduction suggests that it has been a global improvement in the environmental efficiency of Spanish production system.

Despite the negative changes in emission multipliers, note that the two effects involved behaved in an asymmetric way. While the ecological impacts of production processes contributed positively to reduce the environmental burdens, the economic effects contributed negatively to this objective. The distinct behaviour between the economic and the ecological relationships taking place within the production system illustrates the importance of considering the different channels that may modify the impacts on the environment. Our results suggest that not only the own emissions of sectors are important but also the emissions that activities generate because of their intersectorial relationships with all the others.

By identifying the economic and ecological relations that cause pollutant emissions we can precise which are the reasons that contribute to pollution generation and pollution changes within production system. The analytical context presented in this paper extends the knowledge about the underlying effects that modify the environmental efficiency of production sphere and, consequently, it can help to improve the environmental efficiency of an economy.

IV. CONCLUSIONS

The environmental input-output framework allows to separately evaluate how the ecological and the economic relations within the production system contribute to global multiplier modifications. The division of the multipliers' changes into ecological and economic components provides additional information about the complex process of pollution generation.

This paper has analysed the changes in Spanish emission multipliers during the period 1995-2000, through the division of total changes into ecological and economic impacts. The decomposition analysis revealed that the global reduction in Spanish emission multipliers was the combination of effects behaving in a distinct way. During the period of study, an ecological efficiency in production system was combined with an economic inefficiency. Our results also revealed important differences in the sectorial effects. One important finding is, therefore, that there are significant disparities in the way and the intensity that individual activities affect the emission multipliers, and there are also differences in the individual ecological and economic impacts involved. This evidence suggests that the gas emissions of production activities are very asymmetric and no general patterns can be traced.

The analytical approach used in this paper reveals interesting results that may help the policy definition and policy implementation. In this sense, the input-output methodology seems to be an appropriate method to examine the environmental consequences of industrial activity as it allows the sectorial effects to be reflected in an individual way. Another advantage of the environmental input-output model is that makes it possible the dynamic analysis of pollution generation and gas emissions. All of this constitutes a very rich area of exploration by both the economic and the ecological research.

REFERENCES

1. V. Alcántara and J. Roca, Energy and CO_2 Emissions in Spain: Methodology of Analysis and Some Results for 1980-1990, *Energy Economics* **17** (1995) 221-230.

2. I. Butnar, B. Gallego, M. Llop, and F. Castells, Atmospheric Emissions and Structural Path Analysis in the Spanish Economy, mimeo (2005).

3. M. A. Cadarso, and A. Fernández-Bolaños, Patterns of Growth and Consumption and their Influence on the Environment in Spain. Fourteenth International Conference on Input-Output Techniques. Montreal. Canada (1995).

4. S. D. Casler and B. Hannon, Readjustment Potentials in Industrial Energy Efficiency and Structure, *Journal of Environmental Economics and Management* **17** (1989) 93-108.

5. J. M. Gowdy and J. L. Miller, Technological and Demand Change in Energy Use: An Input-Output Analysis" *Environment and Planning A* **19** (1987) 1387-1398.

6. X. Han and T. K. Lakshmanan, Structural Changes and Energy Consumption in the Japanese Economy 1975-1985: An Input-Output Analysis, *Energy Journal* **15** (1994) 165- 188.

7. INE, Cuentas Satélite sobre Emisiones Atmosféricas. Serie 1995-2000, Instituto Nacional de Estadística, Madrid, 2001.

8. INE, Marco Input-Output. Serie 1995-2000, Instituto Nacional de Estadística, Madrid, 2005.

9. S. Kagawa and H. Inamura, A Structural Decomposition of Energy Consumption Based on a Hybrid Rectangular Input-Output Framework: Japan's Case, *Economic Systems Research* **13** (2001) 339-363.

10. M. Lenzen, Primary Energy and Greenhouse Gases Embodied in Australian Final Consumption: An Input-Output Analysis, *Energy Policy* **26** (1998) 495-506.

11. M. Lenzen, L. L. Pade and J. Munksgaard, CO_2 Multipliers in Multi-Region Input-Output Models, *Economic Systems Research* **16** (2004) 391-412.

12. Miller. R. E. and Blair. P. D., Input-Output Analysis: Foundations and Extensions, Prentice-Hall International, New Jersey, 1985.

13. A. Rose and S. Casler, Input-Output structural decomposition analysis: a critical appraisal, *Economic Systems Research* **8** (1996) 33-62.

14. M. Wier, Sources of Changes in Emissions from Energy: A Structural Decomposition Analysis, *Economic Systems Research* **10** (1998) 99-112.

TABLE I
Sectors of Production and Gases

j	**Sectors of Production**	*k*	**Gases**
1	Agriculture	1	Sulphur Oxide (SO_x) *tons*
2	Energy	2	Nitrogen Oxide (NO_x) *tons*
3	Metals	3	No Methane Volatile Organic Compounds (NMVOC) *tons*
4	Minerals	4	Methane (CH_4) *tons*
5	Chemistry	5	Carbon Oxide (CO) *tons*
6	Machinery	6	Carbon Dioxide (CO_2) *thousand of tons*
7	Automobiles	7	Nitrous Oxide (N_2O) *tons*
8	Food	8	Ammonia (NH_3) *tons*
9	Textiles	9	Sulphur Hexafluoride (SF_6) *kilograms*
10	Paper	10	Hydrofluorocarbons (HFC) *kilograms*
11	Other Industry	11	Perfluorocarbons (PFC) *kilograms*
12	Construction		
13	Commerce		
14	Transportation		
15	Finance		
16	Private Services		
17	Public Services		

TABLE II
Changes in Emission Multipliers: $\frac{\Delta \gamma_{kj}}{\gamma_{kj_{1995}}}$ (%)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	Total
SOx	-6.83	-17.57	21.21	-10.24	-21.08	3.13	-14.22	-11.22	-24.33	-16.67	-20.77	-12.85	-19.33	-5.45	-39.05	-22.85	-18.84	**-15.31**
NOx	-1.40	3.58	46.70	-6.50	1.78	34.02	0.22	-6.78	-11.03	-12.92	-5.83	-5.86	-13.05	8.03	-29.81	-27.07	-5.96	**2.84**
NMVOC	-18.22	-14.66	53.42	-9.05	-13.15	26.78	-19.29	-23.15	-27.03	4.09	-9.26	1.35	-29.92	-25.08	-36.09	-24.20	-13.53	**-15.93**
CH_4	-3.77	-49.47	43.45	-32.41	-15.09	2.74	-18.43	-11.48	-34.49	-12.23	-12.04	-19.08	-24.89	-29.78	-44.89	-31.27	-13.84	**-14.22**
CO	-18.78	-13.43	58.75	-8.34	-11.17	26.94	7.96	-26.85	-21.03	10.31	2.17	10.46	-27.28	-45.64	-50.70	-41.98	-16.40	**-11.73**
CO_2	21.14	15.09	66.41	-6.89	11.20	36.28	16.34	15.88	6.74	33.29	10.26	4.11	6.41	29.70	-16.35	-4.63	12.01	**13.44**
N_2O	-49.95	5.63	37.32	-12.89	-27.92	-3.53	-24.47	-52.80	-49.56	-43.11	-34.11	-25.07	-54.16	-10.68	-42.13	-21.05	15.62	**-42.09**
NH_3	-14.88	-22.92	101.78	-21.54	-26.20	15.29	-17.08	-21.56	-36.21	-27.53	-16.45	-19.33	-31.58	-26.80	-39.84	-24.87	-17.51	**-18.56**
SF_6	-81.28	24.93	227.37	52.45	43.50	56.72	67.66	-60.79	-5.23	-3.99	31.44	46.09	-24.22	-54.52	-10.87	41.28	31.72	**18.07**
HFC	96.02	171.22	216.08	131.41	41.83	179.32	87.50	102.72	71.39	87.93	67.89	133.39	174.60	267.61	406.02	1391.19	132.48	**89.18**
PFC	-33.79	-50.32	25.33	-34.94	-36.75	-43.39	-37.08	-36.00	-43.98	-49.80	-41.74	-42.41	-40.16	-26.61	-50.57	-35.43	-41.98	**-38.52**

TABLE III

Decomposition of Changes in Emission Multipliers

Sectors	**Coefficients**		**Economic Effects**		**Ecological Effects**		**Total Effects**	
	Average *A*	Average *B*	Average	%	Average	%	Average	%
1. Agriculture	-0.00005	-1.3676	-0.03576	-0.978%	-0.16764	-4.587%	-0.20340	-5.566%
2. Energy	0.00943	-1.9912	0.22839	6.250%	-0.33826	-9.256%	-0.10987	-3.006%
3. Metals	0.00656	0.7120	0.03846	0.011%	0.04523	1.238%	0.08369	2.290%
4. Minerals	0.00155	-0.1541	0.00786	0.215%	-0.01397	-0.382%	0.00611	0.167%
5. Chemistry	0.00233	0.1128	0.03866	1.058%	0.01623	0.444%	0.05489	1.502%
6. Machinery	0.02442	-0.3812	0.15811	4.327%	-0.05627	-1.539%	0.10184	2.787%
7. Automobiles	0.00307	-0.0550	0.00204	0.056%	-0.00545	-0.149%	0.00341	0.093%
8. Food	-0.00076	-0.1156	-0.04838	-0.013%	-0.01379	-0.377%	-0.06217	-1.701%
9. Textiles	-0.00009	-0.0541	-0.01274	-0.349%	-0.00577	-0.158%	-0.01851	-0.506%
10. Paper	-0.00103	0.1598	-0.00951	-0.260%	0.02103	0.575%	0.01152	0.315%
11. Other Industry	0.00324	-0.0766	0.01655	0.453%	-0.00878	-0.240%	0.00777	0,213%
12. Construction	-0.00034	-0.0079	0.00390	0.107%	-0.00078	-0.021%	0.00312	0.085%
13. Commerce	-0.00069	-0.0163	-0.01647	-0.451%	-0.00219	-0.060%	0.01866	0.511%
14. Transportation	0.00573	-0.3628	0.04129	1.129%	-0.05887	-1.611%	-0.01758	-0.481%
15. Finance	-0.00417	0.0030	-0.02343	-0.641%	-0.00067	-0.018%	-0.02410	-0.659%
16. Private Services	0.00641	-0.5586	0.05142	1.407%	-0.08922	-2.441%	-0.03780	-1.034%
17. Public Services	0.00058	-0.0758	0.00287	0.079%	-0.00495	-0.135%	-0.00208	-0.057%
Total	**0.00331**	**-0.2491**	**0.41446**	**11.341%**	**-0.68411**	**-18.720%**	**-0.26965**	**-7.379%**