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Calculation of Emission Multipliers inItaly, Spain and Germany (1995-2009). An Environmental Input Output Analysis

Introduction

Human activities is linked to substantial pressures to the environment in terms of resource use, pollution and, more generally, environmental degradation. Pressures arise because of production and consumption activities. Environmental impacts of pressures related to human activities are increasingly visible and may lead to irreversible changes to the ecosystems, thus threatening the capacity of humanity to maintain its current living standard in the future. For these reasons, in recent years the investigation of the patterns of environmental pressures has received the attention of both economists and ecologists and became a major field of application of I-O analysis. WassilyLeontief first considered pollution as undesirable or bad output (externalities) in the economy and included environment factors by expanding I-O model framework (Leontief, 1970).

Environmental input output analysis is a general and useful technique for quantifying the changes in the level of pollutant and toxic gas emissions caused by changes in the final demand of goods.The input-output model is helpful to quantify the amount of output and corresponding emissions driven by final consumption (by sector) along the whole supply chain. This is particularly useful when the aim is to quantify the extent to which changes in the level and composition of final demand of a country generates changes in aggregate environmental performance. The literature exploring environmental pressures by using input-output models has flourished in recent years, with many contributions applying decomposition techniques to assess the various drivers of aggregate environmental pressures or emission multipliers (among others, Llop, 2007; Lenzen, 2008).

Our analysis, based on three EU countries (Italy, Spain and Germany) for the period 1995-2009, shows substantial reductions in emissions multipliers for most sectors and types of emission, with the decreasing trend being particularly strong after 2001-2002. Moreover, countries with initially greater emission multipliers experienced faster improvements, coherent with a convergence pattern across EU countries. Going beyond aggregate regularities, we observe substantial heterogeneity across sectors, emissions and countries in terms of level and patterns of emissions multipliers which are worth to be investigated.

The paper is organized as follows. Section 1 discusses the methodology applied to compute emissions multipliers. Section 2 describes data sources. Section 3 comments on the main results and section 4 concludes.

1 Methodology

To examine the economic and environmental impacts associated with air emissions, we employ environmental input-output (EIO) technique that have been widely used for economic analysis since the 70s. Like input-output models, EIOs are static and linear models. According to Wassily Leontief Input-Output can be defined as:

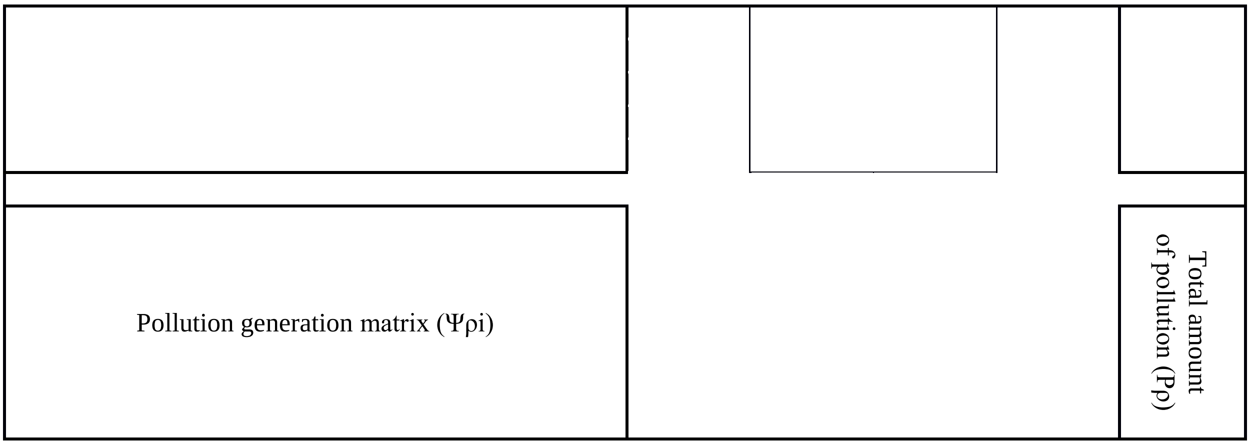
... input-output analysis describes and explains the level of input of each sector of a given national economy in terms of its relationships to the corresponding levels of activities in all the other sectors (Leontief, 1970, pp. 262).

Fundamentally, this involves a matrix representation of the economy in order to predict the effect of changes in one industry on others, while at the same time modelling the effect of this interaction on consumers, the government, and foreign suppliers. Table (1) presents the demand-driven input-output model of the economy by including pollution generation matrix as a result of production process.

Table 1: Pollution generation included in a demand driven input output table Source: MartinezdeAnguita and Wagner (2010).

Receipts		**Expenditures**							
		Industry			**Final demand**			**Exports**	**Total output**
		1	………	N					
Industry	**1**	Z_{11}	………	Z_{1n}	y1H	y1G	y1In	e1	x1
	⋮	⋮	⋱	⋮	⋮	⋮	⋮	⋮	⋮
	N	Z_{n1}	………	Z_{nn}	ynH	ynG	ynIn	en	xn
Value added		WL1	………	WLn	WLH	WLG	WLIn	Wle	L
		WK1	………	WKn	WKH	WKG	WKIn	Wke	K
Imports		m1	………	mn	mH	mG	mIn	me	M
Total Outlay		x1	………	xn	H	G	In	E	
Pollution generation		*Ψ11*	………	*Ψ1*					P1
		⋮	⋱	⋮					⋮
		Ψρ1	………	*Ψρn*					Pρ

Industry Transactions Matrix (Zij)			Final demand (yi)		Indus try outpu



Goods and services are produced either for final consumption or for use in further production. The output is sold to other domestic sectors as intermediate goods for the production process or for final consumption to the different agents such as households, governments, investment or to foreigner customer. That is:

$$\begin{gathered} X_1 = Z_{11} + Z_{12} + \cdots Z_{1n} + Y_1 \\ \vdots \\ X_n = Z_{n1} + Z_{n2} + \cdots Z_{nn} + Y_n \end{gathered} \qquad (1)$$

Where:

Z_{ij} : ouput of ith product used as input in jth industry

X_i: total output of the ith product, i =1, 2…, n

Y_i : total final use of ith product

Equation above can be rewritten as:

$$\begin{gathered} X_1 = a_{11}X_1 + a_{12}X_2 + \cdots a_{1n}X_n + Y_1 \\ \vdots \\ X_n = a_{n1}X_1 + a_{n2}X_2 + \cdots a_{nn}X_n + Y_n \end{gathered} \qquad (2)$$

, (1<i<n) (3)

Denoting, $a_{ij} = \frac{z_{ij}}{x_j}$for the input output coefficient representing the output of sector i absorbed by sector j per unit of output of sector j, and assuming it to be constant, In matrix notation:

$$\begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \vdots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} . \begin{bmatrix} X_1 \\ \vdots \\ X_n \end{bmatrix} + \begin{bmatrix} y_1 \\ \vdots \\ y_n \end{bmatrix} \qquad (4)$$

In standard representation of matrix form:

X = AX + Y⇔ (I-A) X = Y ⇔ X = (I-A)-1 Y = LY; (5)

Equation (5) illustrates how production X would respond to a change in demand Y, including all intermediate production. TheL term called Leontief inverse matrix.

The pollution generation matrix can beadded to the conventional I/O model and expressed as:

$$\begin{gathered} \Psi_{11} + \cdots + \Psi_{1n} = P_1 \\ \vdots \\ \Psi_{\rho 1} + \cdots + \Psi_{\rho n} = P_\rho \end{gathered} \qquad (6)$$

The extended of a demand driven I/O model that the external effects included can be written as the following equations:

$$\begin{gathered} x_1 - a_{11}x_1 - \cdots - a_{1n}x_n = y_1 \\ \vdots \\ x_n - a_{n1}x_1 - \cdots - a_{nn}x_n = y_n \\ \\ P_1 - \varphi_{11}x_1 - \cdots - \varphi_{1n}x_n = 0 \\ \vdots \\ P_\rho - \varphi_{\rho 1}x_1 - \cdots - \varphi_{\rho n}x_n = 0 \end{gathered} \qquad (7)$$

Where:

$\varphi_{\rho j} = \frac{\Psi_{\rho j}}{x_j}$: denotes the amount of the ρ th pollutant emitted by the jth industry.

In matrix notation:

$$\begin{bmatrix} x_1 \\ \vdots \\ x_n \\ 0 \\ \vdots \\ 0 \end{bmatrix} - \begin{bmatrix} a_{11} & \cdots & a_{1n} & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} & 0 & \cdots & 0 \\ -\varphi_{11} & \cdots & -\varphi_{1n} & 1 & \cdots & 0 \\ \vdots & \ddots & \vdots & 0 & \ddots & 0 \\ -\varphi_{\rho 1} & \cdots & -\varphi_{\rho n} & 0 & \cdots & 1 \end{bmatrix} \cdot \begin{bmatrix} x_1 \\ \vdots \\ x_n \\ P_1 \\ \vdots \\ P_\rho \end{bmatrix} = \begin{bmatrix} y_1 \\ \vdots \\ y_n \\ 0 \\ \vdots \\ 0 \end{bmatrix} \tag{8}$$

$$\begin{bmatrix} x \\ 0 \end{bmatrix} - \begin{bmatrix} A & 0 \\ -P & I \end{bmatrix} \cdot \begin{bmatrix} x \\ p \end{bmatrix} = \begin{bmatrix} y \\ 0 \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} I - A & 0 \\ P & -I \end{bmatrix} \cdot \begin{bmatrix} x \\ p \end{bmatrix} = \begin{bmatrix} y \\ 0 \end{bmatrix} \tag{10}$$

Equation 10 can be solved for the vector $\begin{bmatrix} x \\ p \end{bmatrix}$ giving equation (12):

$$\begin{bmatrix} x \\ p \end{bmatrix} = \begin{bmatrix} I - A & 0 \\ P & -I \end{bmatrix}^{-1} \cdot \begin{bmatrix} y \\ 0 \end{bmatrix} \tag{12}$$

Finally:

$$\begin{bmatrix} x \\ p \end{bmatrix} = \begin{bmatrix} (I - A)^{-1} & 0 \\ P(I - A)^{-1} & -I \end{bmatrix} \cdot \begin{bmatrix} y \\ 0 \end{bmatrix} \tag{13}$$

The predictive relationship between a change in the jth industry's final demand (ΔY) and amount of pollution emitted (ΔP) can be calculated by the following equations:

$$\begin{bmatrix} \Delta P_1 \\ \vdots \\ \Delta P_\rho \end{bmatrix} = P(I - A)^{-1} \begin{bmatrix} \Delta y_1 \\ \vdots \\ \Delta y_n \end{bmatrix} \tag{14}$$

ΔP=P (I-A)-1 ΔY

Equation (14) shows the sectoral emissions and captures the entire sequence between the exogenous shocks in industry's final demand vectors and the consequential impacts on pollutant emission vectors.

The term P $(I-A)^{-1}$ is a pollution multiplier matrix and measures the amount of type ρemission caused by an exogenous and unitary change in the final demand of sector j.

The emission coefficient, P $(I-A)^{-1}$ may also change over time for a number of reasons that some of them are listed below:

Technological change

1. scale economies;
2. Relative price changes;
3. Input substitutions (in response, e.g. to price changes or technological change).

2 Data

The data for the modelling exercise were derived from the worldwide input–output tables (WIOD – www.wiod.org). In order to facilitate the analysis and interpretations of the results, the 35-sector disaggregation of the WIOD database are aggregated into 8 activities based on GTAP classification including:

- Agriculture
- Mining and Extraction
- Processed Food
- Labour intensive Manufacturing
- Capital intensive Manufacturing
- Utility and construction
- Transportation and communication
- Services

Table 2 shows the link between the GTAPclassificationand the WIOD classification.

Table 2: Link between WIOD and GTAP classifications

WIOD Sector	GTAP Classification
C_1	Agriculture
C_2	Mining
C_3	Processed Food
C_4, C_5, C_6, C_{13}, C_{14}, C_{15}, C_{16}	Labour intensive Manufacturing
C_7, C_8, C_9, C_{10}, C_{11}, C_{12}	Capital intensive Manufacturing
C_{17}, C_{18}	Utility and construction
C_{19}, C_{20}, C_{21}, C_{22}, C_{23}, C_{24}, C_{25}, C_{26}, C_{27}	Transportation and Communication
C_{28}, C_{29}, C_{30}, C_{31}, C_{32}, C_{33}, C_{34}, C_{35}	Services

The air emission accounts include CO_2 emissions (in 1000 tonnes) and other air pollutant emissions (in tonnes) by sector including N_2O, CH_4, NOX, SOX, NH_3, NMVOC and CO. In order to facilitate the interpretation of the results, air emissions are aggregated into three different indicators of environmental pressures. CO_2, CH_4 and N_2O are grouped together into the indicator of greenhouse gas (GHG) air emissions according to their global warming potential[1] and they are expressed in terms tonnes of CO_2-equivalent emissions. The second indicator measures the contribution to tropospheric ozone formation and tropospheric ozone precursors (CH_4, NOX, NMVOC and CO) are grouped together according to their tropospheric ozone potential (TOP)[2]. Finally, the last indicator refer to the acidifying potential of air emissions of NOX, SOX and NH_3[3].

3 Results

The main goal of this study is to derive quantitative measures of air emissions multiplier such for CO_2, CH_4, N_2O, NOX, SOX, CO, SO_2, and NMOVC for 8 sectors in Italy, Spain and Germany economies over 1995 to 2009 by means of environmental input output analysis. The application of the model provides us with air pollutant production intensity by each sector. The data were collected from the World Input Output Database tables.

Table 1, 2 and 3 report emissions multipliers (emissions per thousand euro of final demand) by year, country and sector for, respectively, GHG emissions, TOP emissions and acidifying emissions.The general pattern we observe for emissions multiplier is decreasing, especially so starting from 2001-2002. In most cases, emission multipliers are greater for Spain and smaller for Italy and especially Germany, while we observe a general tendency of convergence towards the most efficient country. This is in line with the convergence patterns identified by Marin (2013) for direct emission intensity coefficients in European countries.

The average magnitude of multipliers changes substantially across sectors. GHG multipliers are the highest in the Agriculture sector while they are substantially smaller for Labour intensive manufacturing, Transportation and communication and especially Services.

[1]The global warming potential (GWP) of CO_2 is set to 1, while the GWP of CH_4 is 21 and the GWP of N_2O is 310.
http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Carbon_dioxide_equivalent

[2]The tropospheric ozone potential (TOP) of NVMOC is set to 1, for NOX is 1.22, for CO is 0.11 and for CH_4 is 0.014.
http://www.eea.europa.eu/data-and-maps/data/eea-aggregated-and-gap-filled-air-emission-data-2#tab-additional-information

[3]The acidifying potential of SOX is set to 1/32, the one for NOX is 1/46 and the one for NH_3 is 1/17.
http://www.eea.europa.eu/data-and-maps/indicators/en06-energy-related-emissions-of/energy-related-emissions-of-acidifying-substances

The ranking is similar when considering tropospheric ozone precursors, with Transportation and communication being now in line with capital-intensive manufacturing sectors. Finally, regarding acidification, while Agriculture remains the sector with the greater average emission multipliers, Labour intensive manufacturing sectors are characterized by emissions multipliers similar to the ones of Capital intensive manufacturing sectors, while Services and Transportation and communication show the best performance, with the lowest level of multipliers.

Looking at the ranking of countries by sector and type of emission, Germanycleaerly leads (i.e. lowest emission multipliers) for what concerns manufacturing sectors (both labour-intensive and capital-intensive sectors), transportation and communication and services (except for GHG in which Italy is leader). On the other hand, Spain is the laggard country in most cases, with very few exceptions, notably Agriculture (except TOP) and GHG emissions in Mining. However, Spain shows the best dynamic patterns, being the country which improved the most its emission multipliers for basically all sectors and all types of emission. Italy is generally in between Spain and Germany, both in terms of the level of multipliers and in terms of the pace of improvement of multipliers.

To conclude, we observe that the distance between the country with the greater multiplier and the one with the smaller multiplier shrinks in basically all sector-emission combination, with the exception of agriculture (with stable distances) and GHG emissions in Utility and construction, with Germany experiencing a relative worsening of its environmental performance when compared to Italy and Spain.

4 Conclusion and policy recommendation

The analysis described in the current paper has shed some light on the heterogeneity and evolution of emission multipliers for three European countries and eight sectors. The results discussed in this paper are likely to have relevant policy implications. First, the observed pattern of convergence across countries in terms of emission multipliers, towards the most efficient country, is likely to be the results of the increasing harmonization in environmental policy stringency across EU countries occurred in the last decades. Many European directives have aimed at harmonizing EU environmental policy and have avoided a ‘race to the bottom’ among EU countries to attract firms with laxer environmental policies. This convergence pattern has been facilitated by the increasing international diffusion of environmentally efficient technologies (e.g. Beise and Rennings, 2005; Dechezlepretre et al, 2011, Hascic et al, 2010).

A second policy implication, less optimistic, relates to the relatively slow pace of improvement of emission multipliers. These slow improvements have been accompanied and partly compensated by increasing levels of final consumption in all countries. While, on the one hand improvements in emission intensity are crucial to achieve better aggregate environmental performances and improve environmental quality, the increase in the scale of final consumption is still substantial. To generate drastic improvements in environmental quality, policies should be targeted at facilitating more radical improvements in emission multipliers and, eventually, intervene to redirect final demand towards less emission intensive patterns of consumption.

Figure 1: Emission multipliers for greenhouse gas emissions.

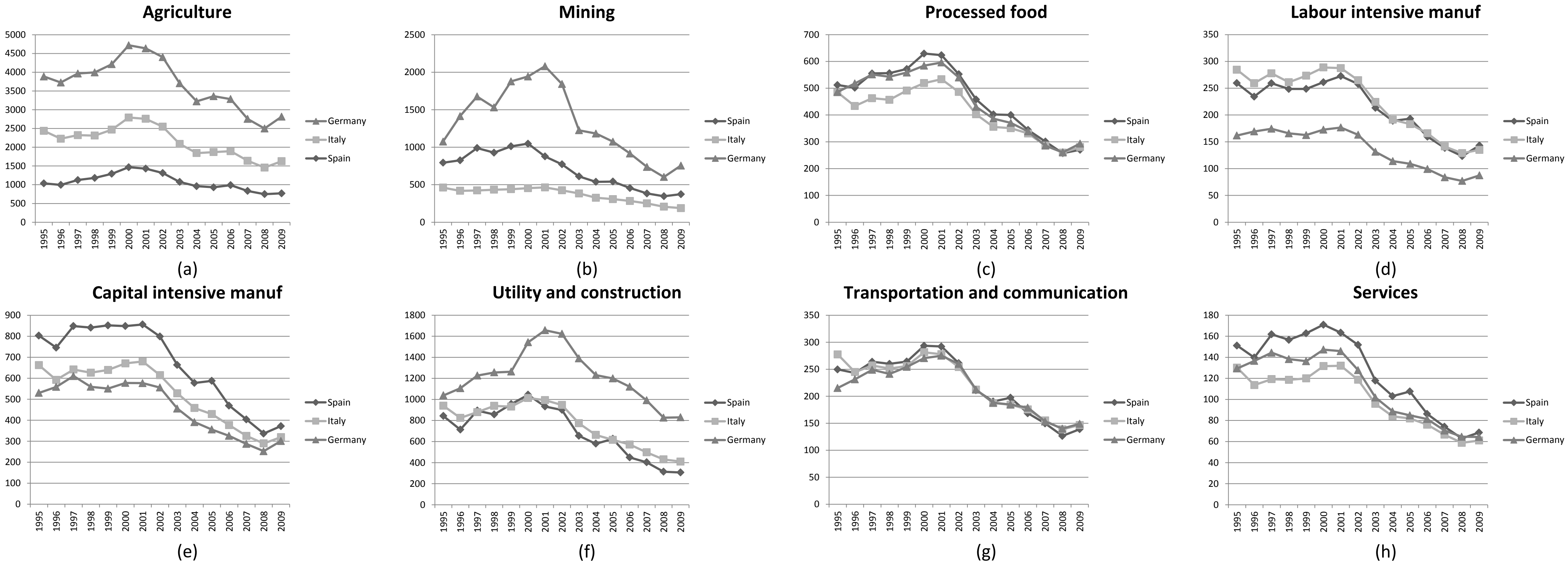


Figure 2: Emission multipliers for tropospheric ozone precursor emissions.

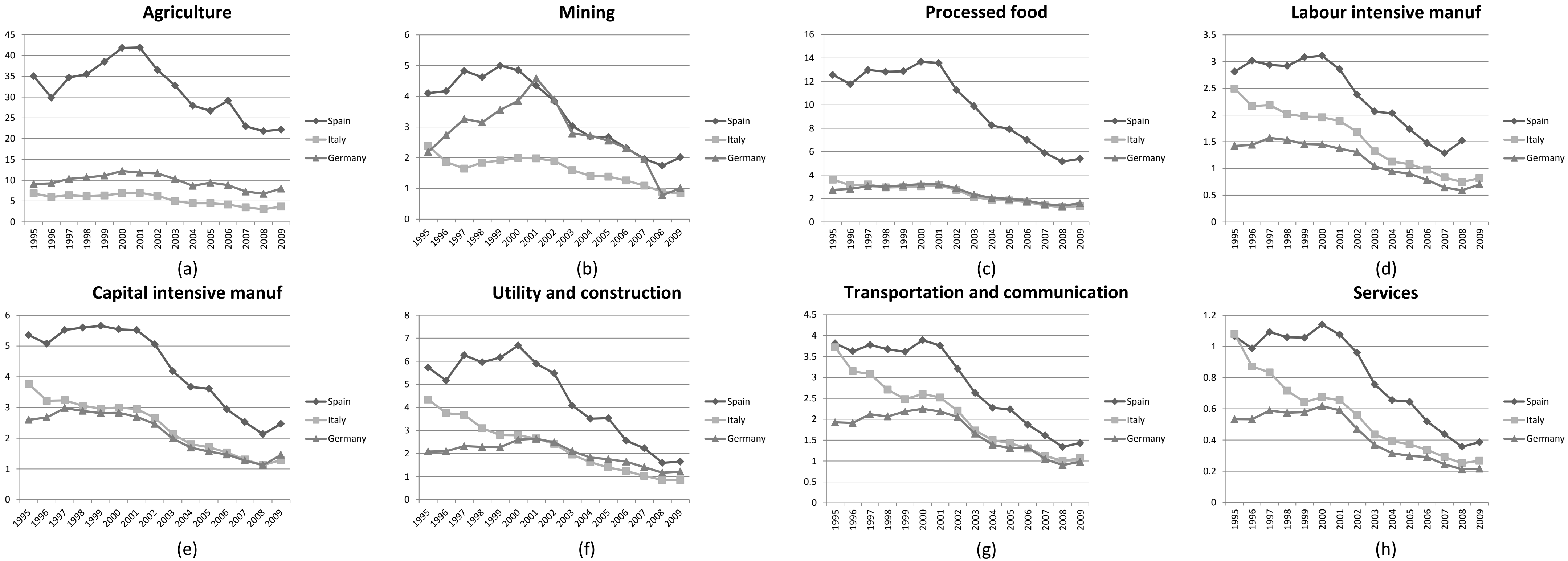
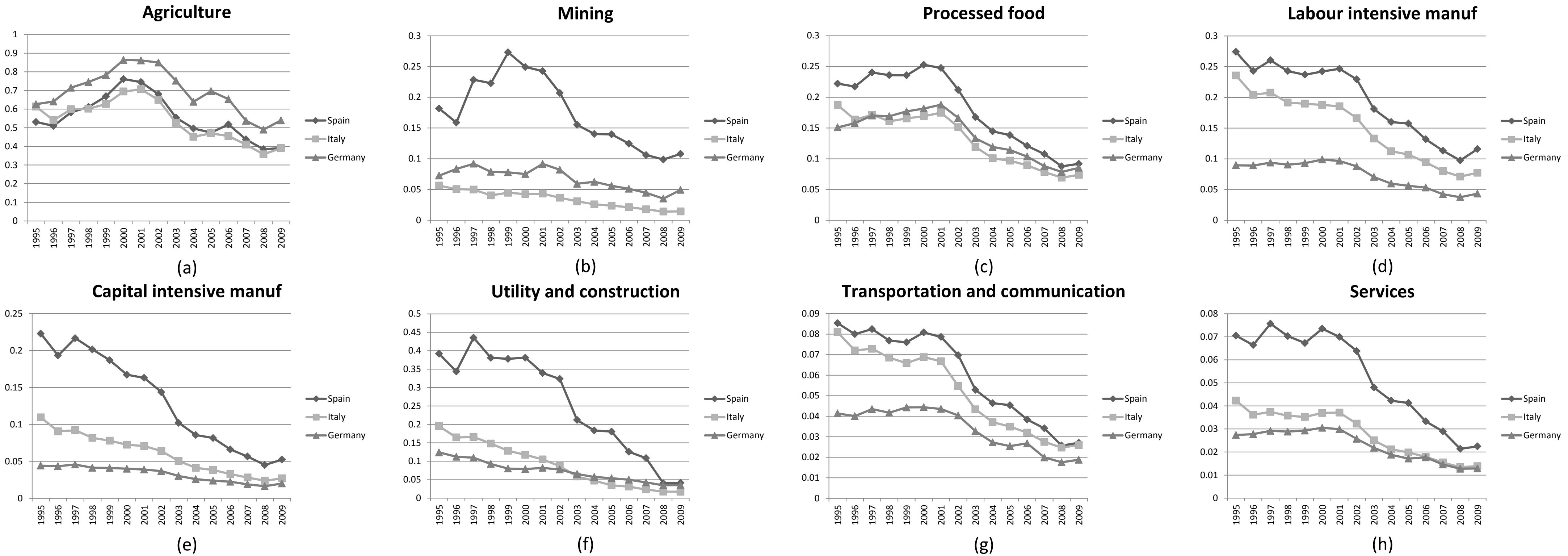


Figure 3: Emission multipliers for acidifying emissions.



Summary in English

The aim of this paper is to derive quantitative measures of air emissions multiplier such as CO_2, CH_4, N_2O, NO_X, SO_X, CO, SO_2, and NMOVC for 8 sectors in Italy, Spain and Germany economy over 1995 to 2009 by means of environmental input output analysis. The application of the input output model provides us with air pollutant production intensity by each sector. The data are obtained from the World Input Output Database, 1995-2009.

The contribution of this paper is the calculation of emission multipliers that account for direct and total emissions of pollutants per unit of demand in 8 economy sectors. The results of this study demonstrate that during the period of studied, all countries, experienced significant improvement in the ecological efficiency of production activities, with decreasing emissions multipliers.

Keywords in English: environmentally extended input output analysis, social accounting matrix.

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