UNIVERSITAT ROVIRA I VIRGILI

WORKING PAPERS

Col·lecció "DOCUMENTS DE TREBALL DEL DEPARTAMENT D'ECONOMIA"

Structural decomposition analysis and input-output subsystems: An application to Spanish CO_2 emissions

Isabela Butnar
Maria Llop

Document de treball nº - 11- 2010

DEPARTAMENT D'ECONOMIA
Facultat de Ciències Econòmiques i Empresarials

Edita:

Departament d’Economia
http://www.fcee.urv.es/departaments/economia/public_html/index.html
Universitat Rovira i Virgili
Facultat de Ciències Econòmiques i Empresarials
Avgda. de la Universitat, 1
432004 Reus
Tel. +34 977 759 811
Fax +34 977 300 661

Dirigir comentaris al Departament d’Economia.

Dipòsit Legal: T - 1840 - 2010

ISSN 1988 - 0812

DEPARTAMENT D’ECONOMIA
Facultat de Ciències Econòmiques i Empresarials

Structural decomposition analysis and input-output subsystems: An application to Spanish CO_2 emissions

Isabela Butnar

Departament d'Enginyeria Química, Universitat Rovira i Virgili, Campus Sescelades, 43007 Tarragona, Spain

Maria Llop*

Departament d'Economia, Universitat Rovira i Virgili, Avgda. Universitat nº 1, 43204 Reus, Spain

Abstract

Analysis of gas emissions by the input-output subsystem approach provides detailed insight into pollution generation in an economy. Structural decomposition analysis, on the other hand, identifies the factors behind the changes in key variables over time. Extending the input-output subsystem model to account for the changes in these variables reveals the channels by which environmental burdens are caused and transmitted throughout the production system. In this paper we propose a decomposition of the changes in the components of CO_2 emissions captured by an input-output subsystems representation. The empirical application is for the Spanish service sector, and the economic and environmental data are for years 1990 and 2000. Our results show that services increased their CO_2 emissions mainly because of a rise in emissions generated by non-services to cover the final demand for services. In all service activities, the decomposed effects show an increase in CO_2 emissions due to a decrease in emission coefficients (i.e., emissions per unit of output) compensated by an increase in emissions caused both by the input-output coefficients and the rise in demand for

* Corresponding author. Tel: +34 977 759898; fax: +34 977 759810. E-mail address: maria.llop@urv.cat.

services. Finally, large asymmetries exist not only in the quantitative changes in the CO_2 emissions of the various services but also in the decomposed effects of these changes.

Keywords: structural decomposition analysis, input-output subsystems, CO_2 emissions, service sector.

1. Introduction

Climate change is one of the most important problems the human race will face in the next decades. There is a current consensus that slowing down the process of climate change requires a global and effective international response. The aim of such a response should be to mitigate the negative impacts of human action on nature in order to preserve the natural habitats of humans in the next generations.

In recent decades, environmental world summits have called for a global agreement to fight climate change. At the same time, research has focused on defining successful and efficient methods to decrease environmental loads caused by the production and consumption processes. This research has not only supplied valuable new information about the negative impacts of economic activity on the environment but also has provided much knowledge about the measures required and their effects on the environment.

The environmental input-output model, which captures the environmental impacts of the production system, identifies pollution transmission throughout the economy. Since the publication of pioneering contributions, the input-output framework has become a useful tool for analysing environmental topics such as water use, pollution generation, energy consumption, and waste generation.

Within the input-output framework, several contributions have developed the so-called subsystems analysis, to study an individual sector or group of sectors that is considered a subsystem which interacts with the rest of the sectors. The basic idea behind the subsystems approach is that an individual sector can be analysed as a particular unit without modifying the main characteristics of the system to which the unit belongs. The usefulness of this approach is that it isolates the relations of a limited number of activities from the whole system, and this provides specific information about the production relations of individual units as part of the entire production sphere. The subsystems model was first proposed by Sraffa (1960) and developed by Pasinetti (1973, 1988), Deprez (1990) and Scazzieri (1990), among others. More recently, Alcántara (1995) and Sánchez-Choliz and Duarte (2003) provided a conceptual set to illustrate the ability of the subsystems approach to show the isolated impacts of individual agents. Alcántara and Padilla (2009) used a subsystem modelisation to study the CO_2 emissions of the Spanish service sector. With a parallel approach, Cardenete and Fuentes (2010) analysed the CO_2 emissions of Spanish energy activities using a subsystem representation within a social accounting matrix model.

Structural decomposition analysis has also been applied in the input-output framework to explore the origin of changes in economic variables. Structural decomposition, which consists of a static comparative method, has become a useful way to isolate the factors behind modifications in input-output models over time. Structural decomposition techniques have been applied to numerous economic issues such as changes in final demand, sectorial technology of production, energy intensities and emission coefficients. For structural decomposition applications to environmental issues, Gowdy and Miller (1987) examined the changes in US energy uses between 1963 and 1977. Casler and Hannon (1989) explored the factors behind the modifications in US energy intensities. Wier (1998) analysed the changes in Danish gas emissions by identifying changes in final demand, changes in input-output coefficients, changes in energy intensities and changes in emissions from the household sector. Kagawa and Inamura (2001) evaluated the sources of changes in energy demand in the Japanese economy. Alcántara and Duarte (2004) compared energy intensities in European Union countries using structural decomposition analysis. Llop (2007) divided the changes in Spanish emissions into changes in structural coefficients and changes in emission coefficients of the input-output model. Peters et al. (2007) analysed how alterations in China's technology, economic structure and lifestyle have modified that country's CO_2 emissions. Wood and Lenzen (2009) combined structural decomposition analysis with structural path analysis in what they called structural path decomposition. Recently, Guerra and Sancho (2010) analysed the effects on Spanish energy uses and emission levels of energy gains, changes in final demand and changes in input requirements. All these contributions focused on explaining the changes in total energy requirements and in total emissions of the economy. It would be interesting, however, to analyse the patterns behind the changes in those emissions caused by a specific sector or group of sectors. This individual analysis would be particularly useful for analysing an economy's most polluting activities. Bearing in mind that climate change demands effective and successful measures, regulators need complete and exhaustive information about the pollution processes, particularly with regard to the most environmentally polluting sectors. Despite the usefulness of applying structural decomposition analysis to a subsystem input-output representation, as far as we know, no contributions in the literature have defined structural decomposition within a subsystem approach.

In this paper we define a structural decomposition context and apply it to an input-output subsystem representation of CO_2 emissions in which, following Alcántara and Padilla (2009), the service sector is treated as a subsystem that generates a single final output, which is the output of all the service sectors. We make an empirical application to the Spanish economy using economic and environmental data for the years 1990 and 2000. With this approach we further analyse pollution generation and provide valuable information about the individual effects of service sectors on air pollution.

Our results show an increase in the CO_2 emissions of all the components captured by the subsystem model for all services during the period analysed. They also show asymmetric contributions of the decomposed sources of changes, and that changes in the final demand for services are the most influential factor behind total emission rises. Finally, there are significant differences in the sectorial effects, not only in terms of quantitative changes in emissions but also in terms of their decomposition into various underlying factors.

The rest of this paper is organised as follows. Section 2 describes the emission subsystem approach and section 3 decomposes the changes of the subsystem components into different effects using structural decomposition techniques. Section 4 contains the empirical results. At the end of the paper we provide some concluding remarks.

2. Input-output subsystems and CO_2 emissions

Our study applies structural decomposition analysis to a subsystem input-output model of pollutant emissions. Analysis of the changes in the emission channels of a particular sector captured by the subsystems approach is helpful for extending our knowledge of the sources of the gas pollution modifications over time.

Under the subsystems approach, a particular sector or a group of sectors is individually analysed without separating it from the rest of the production system. Taking into account that a subsystem responds to the idea of an individual sector or group of sectors that produces a specific commodity, an input-output table allows us to consider as subsystems the sectors of production reflected in the table. In practice, however, the subsystem modelisation groups a few sectors according to similarities between their output, markets, or technology. Following Alcántara and Padilla (2009), in this paper we focus on the service sectors, which are considered as a separated subsystem. We then analyse the patterns behind the evolution of CO_2 emissions of Spanish services between 1990 and 2000.

The starting point for the subsystems representation is the decomposition of the *N* accounts of an input-output system into 1, 2, …, *m* sectors not belonging to the service subsystem, and *m* + 1, …, *n*, belonging to the *s* sectors of the service subsystem. By taking into account this separation of the accounts, the input-output representation can be written as follows:[1]

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix} \begin{pmatrix} x^M \\ x^S \end{pmatrix} + \begin{pmatrix} y^M \\ y^S \end{pmatrix} = \begin{pmatrix} x^M \\ x^S \end{pmatrix}, \tag{1}$$

[1] See Alcántara and Padilla (2009) for a detailed description of the subsystem approach.

where the subscripts and superscripts denote the group of accounts *m* and *s* respectively. In expression (1), matrices *A* contain the technical input-output coefficients, the column vector $x = \begin{pmatrix} x^M \\ x^S \end{pmatrix}$ contains the sectorial production and the column vector $y = \begin{pmatrix} y^M \\ y^S \end{pmatrix}$ contains the final demand. From expression (1), we can calculate sectorial production as $x = (I - A)^{-1} y = By$. By taking this solution into account and assuming that $y^M = 0$, the input-output model is given by:

$$\begin{pmatrix} A_{MM} & A_{MS} \\ A_{SM} & A_{SS} \end{pmatrix} \begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix} \begin{pmatrix} 0 \\ y^S \end{pmatrix} + \begin{pmatrix} 0 \\ y^S \end{pmatrix} = \begin{pmatrix} x_S^M \\ x_S^S \end{pmatrix}, \qquad (2)$$

where x_S^M is the production of non-service sectors needed to cover the final demand of services, and x_S^S is the production of services needed to cover the final demand of services.

Additionally, we can divide matrix *A* of technical coefficients into two submatrices, $A = A^D + A^0$, where A^D contains the elements of matrix *A* in the main diagonal and zeros in the rest, and A^0 contains the other elements of matrix *A* and null values in the main diagonal. By taking this division into account, expression (2) can be transformed as follows:

$$\left[\begin{pmatrix} A_{MM}^D & 0 \\ 0 & A_{SS}^D \end{pmatrix} + \begin{pmatrix} A_{MM}^0 & A_{MS}^0 \\ A_{SM}^0 & A_{SS}^0 \end{pmatrix} \right] \begin{pmatrix} B_{MM} & B_{MS} \\ B_{SM} & B_{SS} \end{pmatrix} \begin{pmatrix} 0 \\ y^S \end{pmatrix} + \begin{pmatrix} 0 \\ y^S \end{pmatrix} = \begin{pmatrix} x_S^M \\ x_S^S \end{pmatrix}. \quad (3)$$

This new expression contains the following two equations:

$$\begin{aligned} &A^D_{MM} B_{MS} y^S + A^0_{MM} B_{MS} y^S + A^0_{MS} B_{SS} y^S = x^M_S \\ &A^D_{SS} B_{SS} y^S + A^0_{SM} B_{MS} y^S + A^0_{SS} B_{SS} y^S + y^S = x^S_S . \end{aligned} \tag{4}$$

The first equation in (4) shows the production of the non-service sectors that is needed to cover the final demand of the services subsystem. As this result shows the effects of services on the other sectors of production, we can consider it as an *external component*. The second equation in (4) shows the production of the service sectors that it is needed to cover the final demand for the service itself. The first term on the left hand side, $A^D_{SS} B_{SS} y^S$, is the amount of own inputs of each service sector required to cover its own final demand, or the *own component*. The second term, $A^0_{SM} B_{MS} y^S$, shows the inputs of the services subsystem required by the non-service sectors to obtain the production that services demand from them. This part can be interpreted as a *feedback component*. The third term, $A^0_{SS} B_{SS} y^S$, contains the production needed by the services from the other services to obtain the own production, or the *internal component*. The last term, y^S, is the final demand for the services subsystem and can be interpreted as a *demand level component*.

To transform expression (4) into an emissions model, we use vectors c^M and c^S which contain the CO_2 emissions per unit of production in the non-service activities and in the service activities, respectively, or the emission coefficients. By taking these vectors into account, the CO_2 emissions associated to the subsystem components are equal to:[2]

$$DLC = c^{S'} y^S ,$$

$$OC = c^{S'} A^D_{SS} B_{SS} y^S ,$$

$$EC = c^{M'}\left(A^D_{MM} B_{MS} + A^0_{MM} B_{MS} + A^0_{MS} B_{SS}\right) y^S ,$$

$$FBC = c^{S'} A^0_{SM} B_{MS} y^S ,$$

$$IC = c^{S'} A^0_{SS} B_{SS} y^S .$$

These expressions show the emissions associated to the demand level component (*DLC*), the own component (*OC*), the external component (*EC*), the feedback component (*FBC*) and the internal component (*IC*). The total (direct and indirect) emissions of the services sector (*E*) can then be calculated as:

$$E = DLC + OC + EC + FBC + IC =$$
$$c^{S'} y^S + c^{S'} A^D_{SS} B_{SS} y^S + c^{M'}\left(A^D_{MM} B_{MS} + A^0_{MM} B_{MS} + A^0_{MS} B_{SS}\right) y^S + c^{S'} A^0_{SM} B_{MS} y^S + c^{S'} A^0_{SS} B_{SS} y^S$$
$$= c^{S'} y^S + c^{S'} L_{OC} y^S + c^{M'} L_{EC} y^S + c^{S'} L_{FBC} y^S + c^{S'} L_{IC} y^S , \qquad (6)$$

where $L_{OC} = A^D_{SS} B_{SS}$, $L_{EC} = (A^D_{MM} B_{MS} + A^0_{MM} B_{MS} + A^0_{MS} B_{SS})$, $L_{FBC} = A^0_{SM} B_{MS}$ and $L_{IC} = A^0_{SS} B_{SS}$ are matrices containing both the intermediate inputs and the final production needed to obtain the final production in the service subsystem.

3. Structural decomposition of the input-output subsystem model

The subsystems approach can be extended to cover the factors behind modifications in the emissions of a particular production unit over time. This analysis is relevant when the approach focuses on a specific sector responsible for a large amount of pollution. In this case, the subsystem model shows the emission channels of a particular activity and the structural decomposition identifies the sources of changes in the emissions caused by this activity.

[2] The symbol (’) denotes transposition of the corresponding matrix or vector.

In the following, we propose a structural decomposition context that is applied to the subsystem model described in section 2. The starting point is the transformation of the total emissions of service sectors (expression (6)) into variations over time as:[3]

$$\Delta E = \Delta DLC + \Delta OC + \Delta EC + \Delta FBC + \Delta IC \, , \qquad (7)$$

containing the changes in each component of the subsystem model. The first term in expression (7) can be approximated through:[4]

$$\begin{aligned} \Delta DLC &= \Delta c^{S'} y^S + c^{S'} \Delta y^S + \Delta c^{S'} \Delta y^S \\ &= \Delta ET_{DLC} + \Delta DT_{DLC} + \Delta CT_{DLC} \, . \end{aligned} \qquad (8)$$

The first element, $\Delta ET_{DLC} = \Delta c^{S'} y^S$, which we call *emission term*, shows the changes in the CO_2 emission intensities of the services subsystem. The second element, $\Delta DT_{DLC} = c^{S'} \Delta y^S$, which we call *demand term*, shows the changes in the demand for services and the last term or *combined term*, $\Delta CT_{DLC} = \Delta c^{S'} \Delta y^S$, shows the combined effects, or the interaction term.[5]

The second element in expression (7) shows the changes in the own component of the subsystem approach:

$$\begin{aligned} &\Delta OC = \Delta c^{S'} L_{OC} y^S + c^{S'} \Delta L_{OC} y^S + c^{S'} L_{OC} \Delta y^S + \\ &\Delta c^{S'} \Delta L_{OC} y^S + \Delta c^{S'} L_{OC} \Delta y^S + c^{S'} \Delta L_{OC} \Delta y^S + \Delta c^{S'} \Delta L_{OC} \Delta y^S = \\ &\Delta ET_{OC} + \Delta IT_{OC} + \Delta DT_{OC} + \Delta CT_{OC} \, , \end{aligned} \qquad (9)$$

---

[3] The symbol (Δ) accompanying a variable denotes the temporal difference in this variable (i.e., final value minus initial value).

[4] Our decomposition uses an additive formula to isolate the effects of changing every matrix of coefficients separately. An alternative decomposition would involve a multiplicative formula that, requiring a more complex means of decomposition than the additive one we use here, would make it difficult to interpret the results.

[5] The combined term, or interaction term, responds to the fact that the first two alterations in the coefficients reflected in expression (8) are entered separately, though they occur simultaneously.

which shows how the own component is affected by the changes in the emission intensity of the services subsystem or *emission term*, $\Delta ET_{OC} = \Delta c^{S'} L_{OC} y^S$, by the changes in the interindustry relations or *interindustry term*, $\Delta IT_{OC} = c^{S'} \Delta L_{OC} y^S$, and by the changes in the final demand for services or *demand term*, $\Delta DT_{OC} = c^{S'} L_{OC} \Delta y^S$. Finally, expression (9) contains the combined effects of the joint alterations or combined term, $\Delta CT_{OC} = \Delta c^{S'} \Delta L_{OC} y^S + \Delta c^{S'} L_{OC} \Delta y^S + c^{S'} \Delta L_{OC} \Delta y^S + \Delta c^{S'} \Delta L_{OC} \Delta y$.

Changes in the external component are equal to:

$$\begin{aligned} &\Delta EC = \Delta c^{M'} L_{EC} y^S + c^{M'} \Delta L_{EC} y^S + c^{M'} L_{EC} \Delta y^S + \\ &\Delta c^{M'} \Delta L_{EC} y^S + \Delta c^{M'} L_{EC} \Delta y^S + c^{M'} \Delta L_{EC} \Delta y^S + \Delta c^{M'} \Delta L_{EC} \Delta y^S = \\ &\Delta ET_{EC} + \Delta IT_{EC} + \Delta DT_{EC} + \Delta CT_{EC}, \end{aligned} \quad (10)$$

which shows the sum of the effects on the external component caused by the changes in the emission coefficients of the non-services subsystem or *emission term*, $\Delta ET_{EC} = \Delta c^{M'} L_{EC} y^S$, the changes in the input-output coefficients or *interindustry term*, $\Delta IT_{EC} = c^{M'} \Delta L_{EC} y^S$, the changes in the final demand for services or *demand term*, $\Delta DT_{EC} = c^{M'} L_{EC} \Delta y^S$ and, finally, the *combined term*, $\Delta CT_{EC} = \Delta c^{M'} \Delta L_{EC} y^S + \Delta c^{M'} L_{EC} \Delta y^S + c^{M'} \Delta L_{EC} \Delta y^S + \Delta c^{M'} \Delta L_{EC} \Delta y$.

Changes in the feedback component are defined as:

$$\begin{aligned} &\Delta FBC = \Delta c^{S'} L_{FBC} y^S + c^{S'} \Delta L_{FBC} y^S + c^{S'} L_{FBC} \Delta y^S + \\ &\Delta c^{S'} \Delta L_{FBC} y^S + \Delta c^{S'} L_{FBC} \Delta y^S + c^{S'} \Delta L_{FBC} \Delta y^S + \Delta c^{S'} \Delta L_{FBC} \Delta y^S = \\ &\Delta ET_{FBC} + \Delta IT_{FBC} + \Delta DT_{FBC} + \Delta CT_{FBC}, \end{aligned} \quad (11)$$

where the first part shows the effects due to changes in the emission coefficients of the services subsystem or *emission term*, $\Delta ET_{FBC} = \Delta c^{S'} L_{FBC} y^S$, the second part shows the effects of the changes in the input-output coefficients or *interindustry term*, $\Delta IT_{FBC} = c^{S'} \Delta L_{FBC} y^S$, the third part shows the effects of changing the demand for services or *demand term*, $\Delta DT_{FBC} = c^{S'} L_{FBC} \Delta y^S$, and the last part shows the *combined term*, $\Delta CT_{FBC} = \Delta c^{S'} \Delta L_{FBC} y^S + \Delta c^{S'} L_{FBC} \Delta y^S + c^{S'} \Delta L_{FBC} \Delta y^S + \Delta c^{S'} \Delta L_{FBC} \Delta y$.

To conclude with expression (7), the changes in the internal component can be divided into:

$$\begin{aligned} &\Delta IC = \Delta c^{S'} L_{IC} y^S + c^{S'} \Delta L_{IC} y^S + c^{S'} L_{IC} \Delta y^S + \\ &\Delta c^{S'} \Delta L_{IC} y^S + \Delta c^{S'} L_{IC} \Delta y^S + c^{S'} \Delta L_{IC} \Delta y^S + \Delta c^{S'} \Delta L_{IC} \Delta y^S = \\ &\Delta ET_{IC} + \Delta IT_{IC} + \Delta DT_{IC} + \Delta CT_{IC}, \end{aligned} \qquad (12)$$

which shows the effects on the internal component caused by changes in the emission coefficients of the service subsystem or *emission term*, $\Delta ET_{IC} = \Delta c^{S'} L_{IC} y^S$, the effects of changes in the interindustry relations or *interindustry term*, $\Delta IT_{IC} = c^{S'} \Delta L_{IC} y^S$, the effects of changes in the final demand or *demand term*, $\Delta DT_{IC} = c^{S'} L_{IC} \Delta y^S$, and the combination of the preceding changes or *combined term*, $\Delta CT_{IC} = \Delta c^{S'} \Delta L_{IC} y^S + \Delta c^{S'} L_{IC} \Delta y^S + c^{S'} \Delta L_{IC} \Delta y^S + \Delta c^{S'} \Delta L_{IC} \Delta y$.

Expressions (7) to (12) show which part of the modifications in the components of the subsystem model (i.e., demand level component, own component, feedback component, external component and internal component) is caused by an alteration in the emission intensities or emission coefficients, by an alteration in interindustry relations or input-output coefficients, and by a modification in the final demand for services. This division clarifies the sources of changes in the CO_2 pollution of services and provides deeper insights into the environmental consequences of the production system.

The decomposition used also allows us to calculate the total contribution of each source of alteration to the total changes in CO_2 emissions, by applying the following formula:

$$\begin{aligned}
&\Delta E = \Delta ET + \Delta IT + \Delta DT + \Delta CT = \\
&\Delta ET_{DLC} + \Delta ET_{OC} + \Delta ET_{EC} + \Delta ET_{FBC} + \Delta ET_{IC} + \\
&\Delta IT_{DLC} + \Delta IT_{OC} + \Delta IT_{EC} + \Delta IT_{FBC} + \Delta IT_{IC} + \\
&\Delta DT_{DLC} + \Delta DT_{OC} + \Delta DT_{EC} + \Delta DT_{FBC} + \Delta DT_{IC} + \\
&\Delta CT_{DLC} + \Delta CT_{OC} + \Delta CT_{EC} + \Delta CT_{FBC} + \Delta CT_{IC},
\end{aligned} \tag{13}$$

which identifies the total changes in emissions caused by modification in the emission coefficients, in the input-output coefficients and in the final demand for services.

The above structural decomposition explains the reasons for changes in pollutant emissions. In particular, we have determined how CO_2 emissions are modified both by changes in the coefficients and changes in the final demand involved in the subsystem model. This analysis therefore extends our knowledge of how a specific sector or group of sectors affects the environment.

4. Empirical application to Spanish service sectors

The analytical context discussed above allows us to detach the emission channels of a particular subsystem from the entire gas emission processes and illustrates the various components of pollution generation. Structural decomposition techniques allow us to identify the sources of changes accrued in each component of the subsystem approach and provide precise knowledge of the reasons behind the changes in emissions.

For the empirical application we used the symmetric Input-Output (IO) Tables and the National Accounting Matrices including Environmental Accounts (NAMEAs) for the years 1990 and 2000, published by the Spanish Institute of Statistics (INE 1998, 2006, 2009). The level of disaggregation within the 1990 IO table is of 57 sectors and within the 2000 IO tables it is of 73 sectors. In the NAMEAs for these two years, the emissions are allocated to 47 economic sectors. To bring all these data to the same disaggregation level, we aggregated both IO tables and NAMEAs for 1990 and 2000 to 36 economic sectors, 13 of which are the service sectors which are the focus of this work.

The information reported by the model highlights several aspects of the recent evolution in the CO_2 emissions of the Spanish service sector. First we focus on the total changes in the components identified by the subsystems approach. Second, we decompose the total changes of the subsystem components into different effects (changes in input-output coefficients, changes in emission coefficients and changes in the final demand for services). Finally, we analyse how the decomposed effects contribute to total CO_2 emission changes.

4.1. Changes in the subsystem components

Following the logic behind the input-output subsystems representation, the emissions caused by a particular sector can be divided into demand level component, own component, external component, feedback component and internal component. This section quantifies the changes in all the emission components of the Spanish services during the decade 1990-2000. Table 1 and figure 1 illustrate the results, which are calculated from the difference between the values in 2000 and their values in 1990.

[PLACE TABLE 1]

[PLACE FIGURE 1]

All components of the subsystem model show positive changes in CO_2 emissions. Specifically, during the period analysed the total CO_2 pollution of services increased by 25,484 Kt of CO_2, 58% of which (14,689 Kt) was caused by the external component, i.e. by the production of non-service sectors needed to satisfy the final demand of service sectors. In 1990, the external component accounted for 63.4% of the total CO_2 emissions of the service sectors, which shows the important pull effect of the service sectors on the non-service sectors. As Alcántara and Padilla (2009) showed, in the year 2000 this pulling effect of the service sectors was also very important as it was responsible for 61.7% of the total service sector CO_2 emissions and 21.7% of non-service sectors CO_2 emissions. The service sectors with the strongest pull effect seem to be commerce and reparation, hotel and restaurants and real estate and business activities with a share of 43.7%, 71.8% and 14.2%, respectively, in 1990 and of 50.1%, 38.6% and 35%, respectively, in 2000. Table 1 and figure 1 also show that commerce and reparations registered the greatest increase (7,533 Kt), followed by real estate and business activities (6,617 Kt). On the other hand, hotels and restaurants registered a decrease of 2,844 Kt in CO_2 emissions. However, despite the important indirect effects of these service sectors on CO_2 emissions on the national scale, they are still not affected by emissions control policies.

The demand level component is also important, with a share of 25% (6,290 Kt) of the increase in CO_2 emissions from 1990 to 2000. The most important increase in CO_2 emissions due to the increase in final demands was registered in the land transport, air transport and again commerce and reparation sectors. In the case of land transport and air transport, the results are probably underestimated since NAMEA's methodology allocates transportation done with a self-means of transport to the sectors and not to the transport sectors.

Also from the results in table 1 and figure 1, we can see that the own component has the lowest share with 1%, followed by the feedback component with 4% (947 Kt) and the internal component with 12% (3,139 Kt).

To sum up, table 1 and figure 1 indicate that the changes in CO_2 emissions of the Spanish services have important asymmetries at the sectorial level. This suggests that service sectors should be individually treated by environmental measures to avoid inefficient distortions in the production system.

4.2. Decomposition of the changes in the subsystem components

This section presents the empirical results of the structural decomposition described in section 3. Table 2 and figure 2 show the decomposition of the changes in the demand level component into an emission term, a demand term and a combined term, following expression (8) of the model.

[PLACE TABLE 2 HERE]

[PLACE FIGURE 2 HERE]

The demand level component increased by 6,290 Kt of CO_2 during the period 1990-2000, but the significance of the decomposed terms is very different quantitatively. Specifically, the emission term shows a decrease of 5,484 Kt, the demand term shows an increase of 18,510 Kt and the combined term shows a reduction of -6,735 Kt of CO_2. This individual behaviour would suggest that, while the service sectors increased their emission efficiency, i.e. there was a reduction in emissions per unit of production, the high increase in the demand term hindered a reduction in the total CO_2 emissions of the demand level component.

At the sectorial level, the demand term is positive for all activities, and is especially significant in land transport and air transport, which are the services with the greatest increase in the emissions caused by final demand. On the other hand, the emission term is negative in all sectors except public administration (84 Kt) and financial intermediation (0 Kt).

Table 3 and figure 3 contain the decomposition of the changes in the own component, which captures the emissions due to the inputs required from services to cover the final demand for services activities itself.

[PLACE TABLE 3 HERE]

[PLACE FIGURE 3 HERE]

Between 1990 and 2000, the total increase in the own component was 419 Kt of CO_2- This is the result of the following modifications: a reduction of 149 Kt caused by the emission term (which shows the changes in emission coefficients), an increase of 320 caused by the interindustry term (which shows the changes in input-output coefficients), an increase of 907 caused by an increase in the demand for services, and a reduction of 659 due to the combined term. These total effects suggest that despite the improvement in the environmental efficiency of Spanish services, the increase in the final demand and the changes in intermediate transactions brought about an increase in CO_2 emissions of the own component.

Another interesting result from table 3 and figure 3 is that the changes in the own component are very different at the sectorial level. Commerce and reparations is the service that most changed its own component, followed by other services. If we look at the various terms of the decomposition analysis, we can see that the demand term increased in all services and the emission term decreased in all services.

[PLACE TABLE 4 HERE]

[PLACE FIGURE 4 HERE]

Table 4 shows the division of changes in the external component. The emissions caused by services on the other non-service activities increased by 14,689 Kt. This resulted from a reduction of 13,051 due to changes in emission coefficients, an increase of 1,562 due to changes in input-output coefficients, an increase of 44,293 due to changes in final demand and a reduction of 18,115 due to the combined term. These results reaffirm those from the preceding components of the subsystem model, which suggests that the final demand is responsible for the increases in CO_2 emissions by services.

Again the sectorial trends are very asymmetric, with quantitative values that go beyond an increase of 5,793 Kt in real estate and business activities and a reduction of 3,437 Kt in hotels and restaurants. This shows that the effects of services on activities that do not belong to the service subsystem are very different and no generalizations can be made. On the other hand, the different terms of the decomposition can present positive or negative values depending on the sector analysed. Exceptions are the demand term, which has a positive impact on all services, and the emission term, which has a negative impact.

Like the preceding components, feedback contributed positively to changes in emissions. However, the different pollution transmission channels captured by the model provide mixed results. While the contribution of the emission coefficients is negative, the interindustry term and the demand term contributed positively to emission changes. This positive contribution was especially significant for the demand term, which shows that the pollution in Spanish services during the period of analysis was largely explained by a rise in the final demand for services.

[PLACE TABLE 5 HERE]

[PLACE FIGURE 5 HERE]

The last decomposition refers to the internal component, i.e. the effects of services on other services to cover the own production. Again, the emission term caused a reduction in emissions (-1,183 Kt), while the changes in input-output coefficients and the changes in demand caused an increase (1,900 Kt and 4,077 Kt, respectively). The individual effects again depended greatly on the type of service analysed and on the decomposed terms.

[PLACE TABLE 6 HERE]

[PLACE FIGURE 6 HERE]

In summary, study of the changes in the components of the subsystem model reveals the underlying effects that generate environmental consequences within the production system. During the period of analysis, the various sources of changes in emissions by services behaved differently. This illustrates the usefulness of structural decomposition for making detailed analyses of the process of pollutant emissions.

4.3. Total changes in the decomposed terms

This section shows the total modifications in the various terms we have identified within each of the changes in the subsystem components. From expression (13) above, the total changes in the CO_2 emissions of services can be divided into a total emission term, a total interindustry term, a total demand term, and a total combined term.

[PLACE TABLE 7 HERE]

[PLACE FIGURE 7 HERE]

Table 7 shows that the changes in the different terms involved were substantially different. Between 1990 and 2000, the emission term and the combined term reduced CO_2 emissions by 20,201 Kt and 27,472 Kt, respectively, while the interindustry term and the demand term increased them by 4,163 and 68,994 Kt, respectively. This means that, although services become more environmentally efficient in terms of emissions per unit of output, the final demand and, to a lesser extent, the interindustry relations caused an increase in total emissions. This indicates that efficient policies to decrease emissions in service sectors should focus on reducing demand for service sectors. Special attention should therefore be paid to real estate and business activities and other services.

Figure 7 shows that the demand term generated increases in the emissions of all services that were not compensated by the general decreases in the emission term. On the other hand, the interindustry term shows positive changes in most sectors except hotels and restaurants, financial intermediation, education, health services and public administration.

5. Conclusions

This paper has applied structural decomposition within an input-output subsystem model to show the patterns of CO_2 emissions by Spanish services between 1990 and 2000. Specifically, we have defined a decomposition method that isolates the effects of changing the emission coefficients, the input-output coefficients and the demand level within all the components of the subsystem input-output model. This provides additional information about the complex process of pollution generation and how it is related to services activities.

Our application to the Spanish service sector reveals a general increase in the CO_2 emissions of all the subsystem components (i.e., demand level component, own component, feedback component, external component and internal component). The strongest variation is registered in the external component, which indicates the strong pull effect exerted by the service sectors on the non-service sectors. From the 13 service sectors, we have identified three whose activity pulls on the production of non-service sectors: commerce and reparation, hotel and restaurants and real estate and business activities. Also, during the period of study the emission coefficients contributed negatively to CO_2 changes, which suggests that services increased the environmental efficiency of their production processes. On the other hand, both the final demand and the intersectorial relationships contributed positively to emission changes, with these effects being higher than the reduction caused by the emission coefficients. Another important finding is that there are significant differences in the way the various services behaved not only in terms of their quantitative changes but also in terms of the contribution from each decomposed factor to total emission changes. This suggests that pollution abatement policies focused on services should take into account the particularities of each activity in order not to generate inefficiencies or distortions in the productive system.

The method used in this paper is useful for identifying the underlying effects that contribute to the processes of pollution generation. To fight climate change, both the economic and environmental sciences must improve their methods for capturing the complex relationships taking place in pollution processes. This paper reveals several aspects that can isolate the different sources of changes in emission levels of a specific sector or group of sectors and provides new information about pollution generation processes.

Acknowledgements

We acknowledge the Spanish *Ministerio de Educación y Cultura* (grant SEJ2007-66318) and the *Generalitat de Catalunya* (grants SGR2009-322 and SGR2009-230).

References

Alcántara, V. 1995. Economía y contaminación atmosférica: hacia un nuevo enfoque desde el análisis input-output. Doctoral Thesis Dissertation. University of Barcelona.

Alcántara, V. and Duarte, R. 2004. Comparison of energy intensities in European Union countries. Results of a structural decomposition analysis. Energy Policy 32, 177-189.

Alcántara, V. and Padilla, E. 2009. Input-output subsystems and pollution: an application to the service sector and CO_2 emissions in Spain, Ecological Economics 68, 905-914.

Cardenete, M. A. and Fuentes, P. 2010. Energy consumption and CO_2 emissions in the Spanish economy. In Llop, M. (editor): Air pollution: measurements and control policies, Bentham E-Books, in press.

Casler, S. D. and Hannon, B. 1989. Readjustment potentials in industrial energy efficiency and structure. Journal of Environmental Economics and Management 17, 93-108.

Deprez, J. 1990. Vertical integration and the problem of fixed capital. Journal of PostKeynesian Economics 13, 47-64.

Guerra, A. I. and Sancho, F. 2010. An analysis of primary energy requirements and emission levels using structural decomposition approach: the Spanish case. In Llop, M. (editor): Air pollution: measurements and control policies, Bentham E-Books, in press.

Gowdy, J. M., Miller, J. L. 1987. Technological and demand change in energy use: an input-output analysis. Environment and Planning A 19, 1387-1398.

INE, 2006. Cuentas satélite sobre emisiones atmosféricas. Serie 1990 y 1995-2003. Madrid. Instituto Nacional de Estadística.

INE, 1998. Tablas input-output (bases anteriores a base 95) . Madrid. Instituto Nacional de Estadística.

INE, 2009. Marco input-output. Serie 2000-2006. Madrid. Instituto Nacional de Estadística.

Kagawa, S., Inamura, H. 2001. A structural decomposition of energy consumption based on a hybrid rectangular input-output framework: Japan's case. Economic Systems Research 13, 339-363.

Llop, M. 2007. Economic structure and pollution intensity within the environmental input-output framework. Energy Policy 35, 3410-3417.

Pasinetti, L. 1973. The notion of vertical integration in economic analysis. Metroeconomica 25, 1-29.

Pasinetti, L. 1988. Growing subsystems, vertically hiper-integrated sectors and the labour theory of value. Cambridge Journal of Economics 12, 125-134.

Peters, G. P.; Weber, C. L.; Guan, D. and Hubacek, K. 2007. China's growing CO_2 emissions-a race between increasing consumption and efficiency gains. Environmental Science and Technology 41 (7), 5939-5944.

Sánchez-Choliz, J. and Duarte, R. 2003. Analysing pollution by vertically integrated coefficients, with an application to the water sector in Aragon. Cambridge Journal of Economics 27, 433-448.

Scazzieri, R. 1990. Vertical integration in economic theory. Journal of Post Keynesian Economics 13, 20-46.

Sraffa, P. 1960. Production of commodities by means of commodities. Cambridge University Press, Cambridge.

Wier, M. 1998. Sources of changes in emissions from energy: A structural decomposition analysis. Economic Systems Research 10, 99-112.

Wood, R. and Lenzen, M. 2009. Structural path decomposition. Energy Economics 31, 335-341.

Table 1. Total changes in CO_2 emissions of the subsystem components (Kt)

Services subsectors	ΔDLC	ΔOC	ΔFBC	ΔEC	ΔIC	**Total**
1. Commerce and reparations	1,171	180	139	4,353	1,689	**7,533**
2. Hotels and restaurants	550	15	211	-3,437	-184	**-2,844**
3. Land transport	1,734	61	16	541	176	**2,529**
4. Maritime transport	282	-26	5	63	9	**334**
5. Air transport	1,383	-49	16	304	6	**1,661**
6. Auxiliary transport services	21	94	32	882	828	**1,857**
7. Post and telecommunications	47	15	30	1,232	17	**1,341**
8. Financial intermediation	81	-23	16	447	59	**582**
9. Real estate and business activities	111	50	254	5,793	410	**6,617**
10. Education	196	0	32	1,191	-132	**1,287**
11. Health services	280	8	91	1,342	213	**1,935**
12. Other services	85	95	128	2,786	210	**3,304**
13. Public administration	347	-3	-24	-808	-164	**-651**
Total	**6,290**	**419**	**947**	**14,689**	**3,139**	**25,484**

Figure 1. Total changes in CO_2 emissions of the subsystem components (Kt)

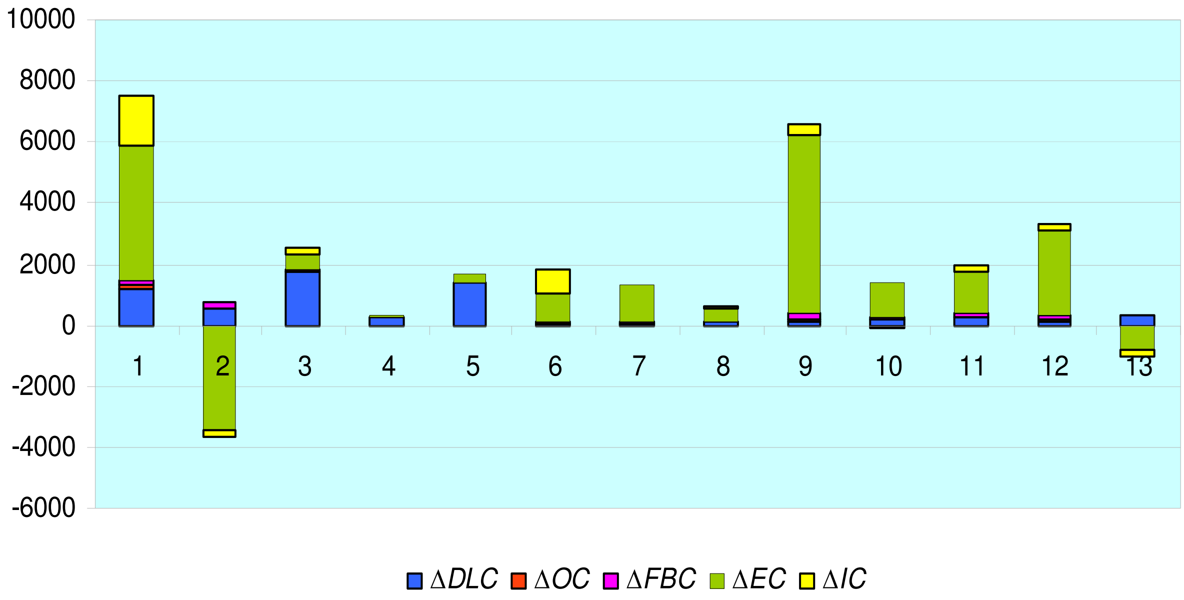

Table 2. Changes in the Demand Level Component: ΔDLC (Kt)

Services subsectors	ΔET_{DLC}	ΔDT_{DLC}	ΔCT_{DLC}	ΔDLC
1. Commerce and reparations	-329	1,724	-224	**1,171**
2. Hotels and restaurants	-635	1,732	-547	**550**
3. Land transport	-1,826	5,318	-1,757	**1,734**
4. Maritime transport	-392	887	-212	**282**
5. Air transport	-1,262	4,176	-1,531	**1,383**
6. Auxiliary transport services	-288	1,375	-1,067	**21**
7. Post and telecommunications	-11	95	-38	**47**
8. Financial intermediation	0	85	-3	**81**
9. Real estate and business activities	-77	355	-167	**111**
10. Education	-135	574	-243	**196**
11. Health services	-253	977	-443	**280**
12. Other services	-362	995	-549	**85**
13. Public administration	84	217	46	**347**
Total	**-5,485**	**18,510**	**-6,735**	**6,290**

Figure 2. Changes in the Demand Level Component: ΔDLC (Kt)

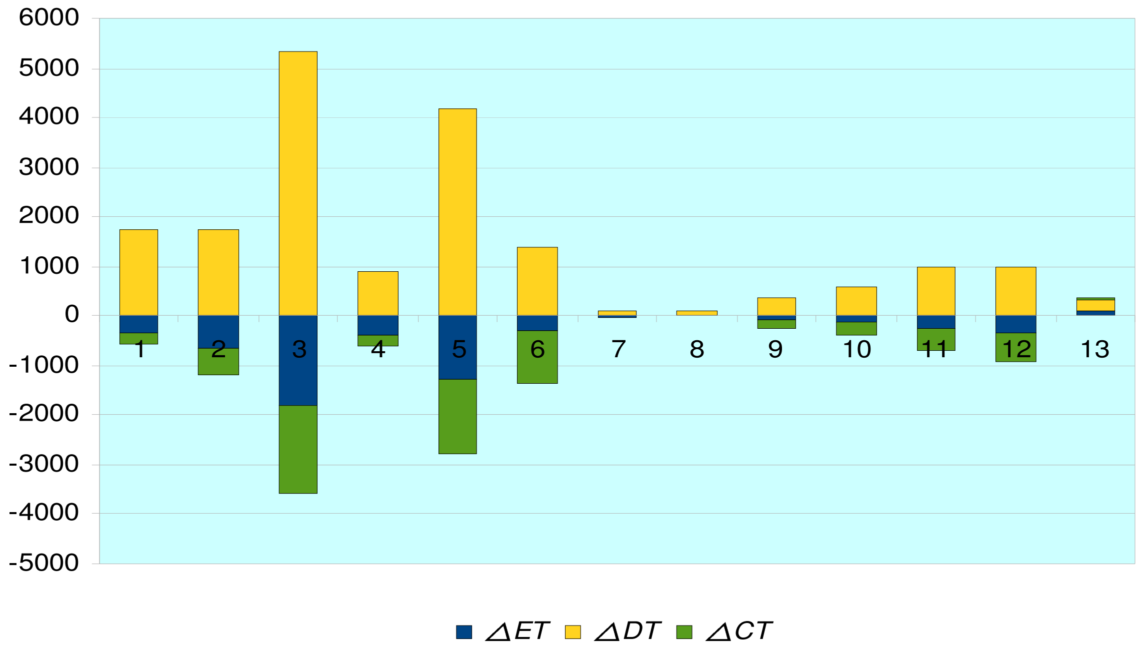

Table 3. Changes in the Own Component: ΔOC (Kt)

Services subsectors	ΔET_{oc}	ΔIT_{oc}	ΔDT_{oc}	ΔCT_{oc}	ΔOC
1. Commerce and reparations	-9	178	42	-30	**180**
2. Hotels and restaurants	-5	20	19	-18	**15**
3. Land transport	-20	65	59	-43	**61**
4. Maritime transport	-8	-18	18	-18	**-26**
5. Air transport	-62	-71	205	-121	**-49**
6. Auxiliary transport services	-2	80	13	3	**94**
7. Post and telecommunications	-1	5	5	5	**15**
8. Financial intermediation	-3	-45	393	-368	**-23**
9. Real estate and business activities	-5	29	34	-9	**50**
10. Education	-2	-1	10	-7	**0**
11. Health services	-19	-8	75	-41	**8**
12. Other services	-6	82	22	-4	**95**
13. Public administration	-6	3	11	-10	**-3**
Total	**-149**	**320**	**907**	**-659**	**419**

Figure 3. Changes in the Own Component: ΔOC (Kt)

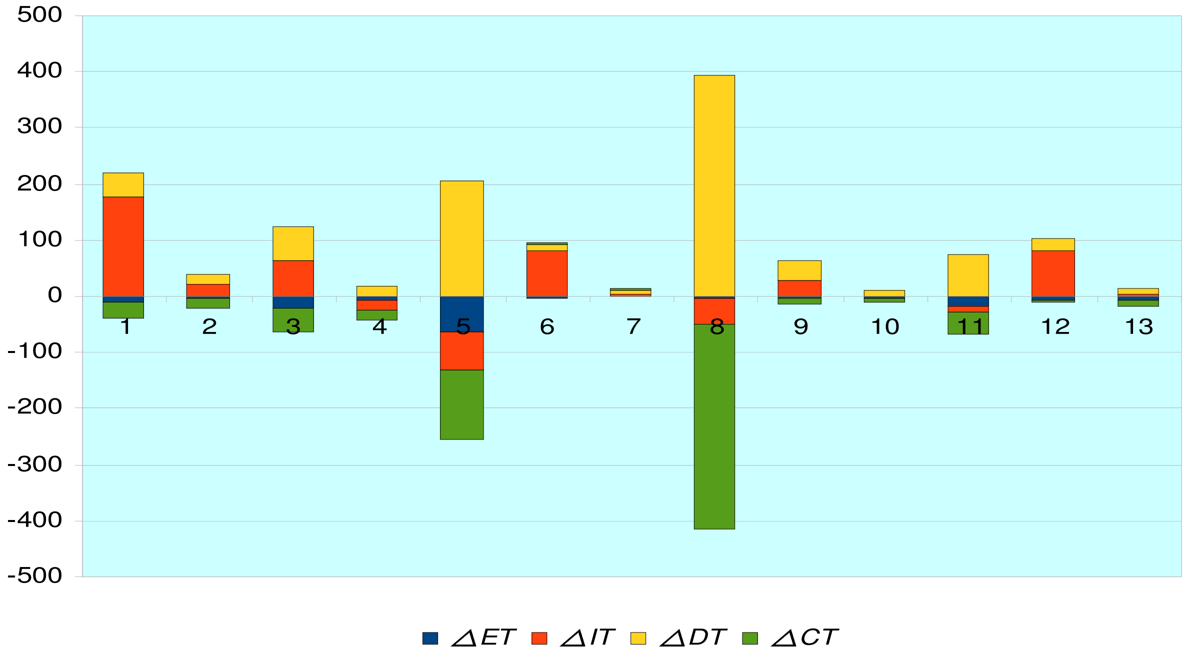

Table 4. Changes in the External Component: ΔEC (Kt)

Services subsectors	ΔET_{EC}	ΔIT_{EC}	ΔDT_{EC}	ΔCT_{EC}	ΔEC
1. Commerce and reparations	-2,621	4,099	5,257	-2,382	**4,353**
2. Hotels and restaurants	-4,199	-4,813	10,923	-5,348	**-3,437**
3. Land transport	-635	10	1,811	-646	**541**
4. Maritime transport	-85	65	132	-48	**63**
5. Air transport	-173	73	605	-201	**304**
6. Auxiliary transport services	-74	175	749	32	**882**
7. Post and telecommunications	-45	343	476	458	**1,232**
8. Financial intermediation	-255	-539	6,109	-4,868	**447**
9. Real estate and business activities	-939	1,858	5,612	-739	**5,793**
10. Education	-427	96	2,300	-777	**1,191**
11. Health services	-886	-265	4,510	-2,017	**1,342**
12. Other services	-542	1,250	2,411	-333	**2,786**
13. Public administration	-2,171	-790	3,398	-1,245	**-808**
Total	**-13,051**	**1,562**	**44,293**	**-18,115**	**14,689**

Figure 4. Changes in the External Component: ΔEC (Kt)

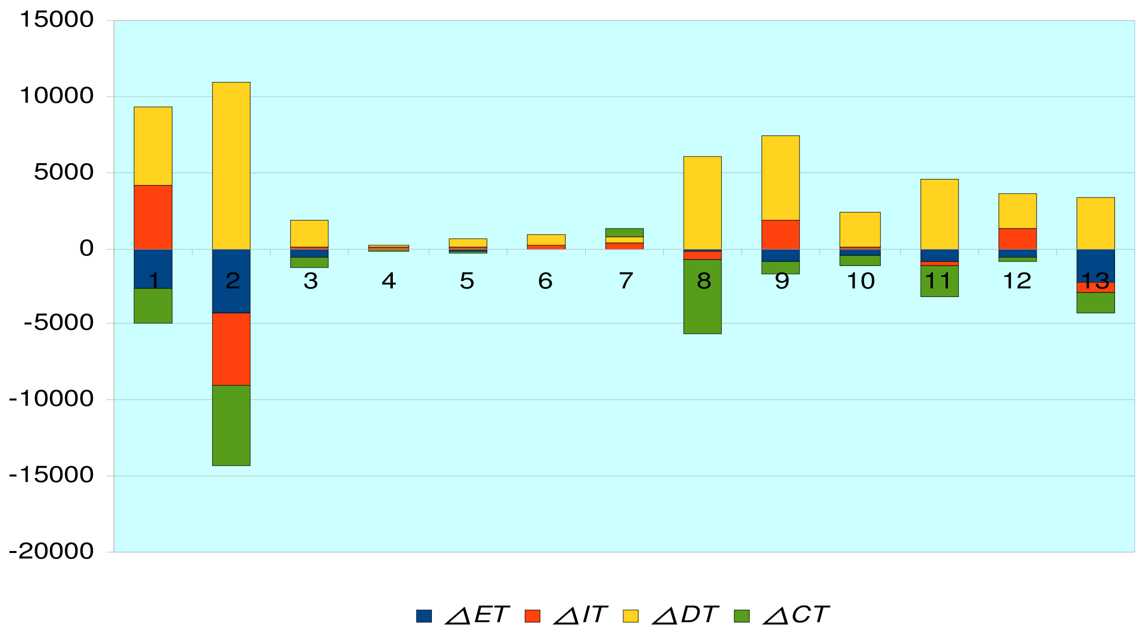

Table 5. Changes in the Feedback Component: ΔFBC (Kt)

Services subsectors	ΔET_{FBC}	ΔIT_{FBC}	ΔDT_{FBC}	ΔCT_{FBC}	ΔFBC
1. Commerce and reparations	-57	115	117	-35	**139**
2. Hotels and restaurants	-131	105	338	-101	**211**
3. Land transport	-11	6	31	-11	**16**
4. Maritime transport	-1	5	2	-1	**5**
5. Air transport	-3	9	10	0	**16**
6. Auxiliary transport services	-2	7	19	8	**32**
7. Post and telecommunications	-1	9	6	15	**30**
8. Financial intermediation	-6	-13	153	-118	**16**
9. Real estate and business	-39	62	257	-27	**254**
10. Education	-9	6	47	-12	**32**
11. Health services	-19	27	102	-18	**91**
12. Other services	-11	66	51	23	**128**
13. Public administration	-44	-24	74	-30	**-24**
Total	**-332**	**381**	**1,206**	**-308**	**947**

Figure 5. Changes in the Feedback Component: $\triangle FBC$ (Kt)

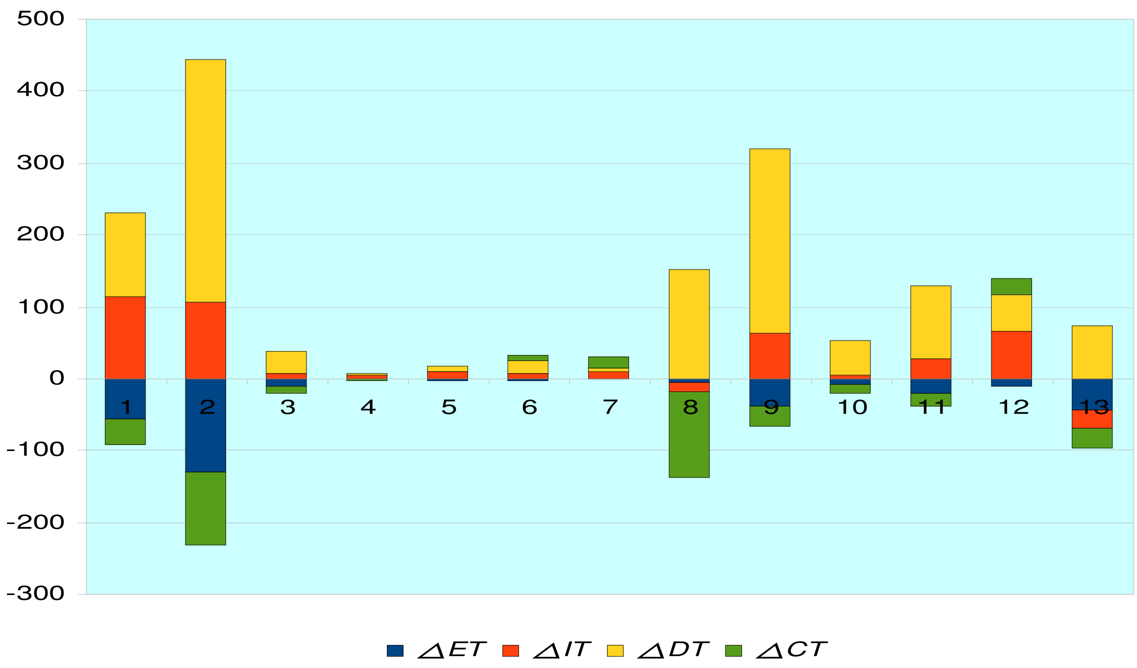

Table 6. Changes in the Internal Component: $\triangle IC$ (Kt)

Services subsectors	ΔET_{IC}	ΔIT_{IC}	ΔDT_{IC}	ΔCT_{IC}	ΔIC
1. Commerce and reparations	-121	1,744	212	-146	**1,689**
2. Hotels and restaurants	-208	-262	569	-283	**-184**
3. Land transport	-138	234	213	-133	**176**
4. Maritime transport	-51	49	44	-32	**9**
5. Air transport	-104	14	193	-97	**6**
6. Auxiliary transport services	-10	253	102	482	**828**
7. Post and telecommunications	-14	-19	142	-92	**17**
8. Financial intermediation	-49	-95	1,051	-848	**59**
9. Real estate and business activities	-56	159	327	-20	**410**
10. Education	-78	-169	394	-279	**-132**
11. Health services	-44	66	214	-22	**213**
12. Other services	-55	81	230	-44	**210**
13. Public administration	-255	-155	388	-141	**-164**
Total	**-1,183**	**1,900**	**4,077**	**-1655**	**3,139**

Figure 6. Changes in the Internal Component: ΔIC (Kt)

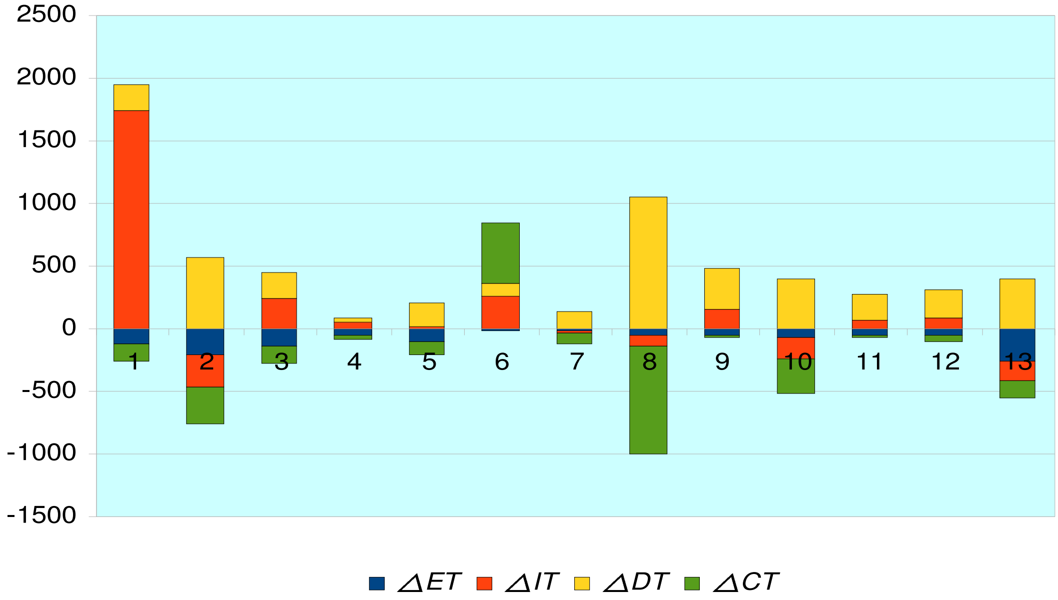

Table 7. Total changes in the decomposed terms (Kt)

Services subsectors	ΔET	ΔIT	ΔDT	ΔCT	Total
1. Commerce and reparations	-3,137	6,136	7,351	-2,817	**7,533**
2. Hotels and restaurants	-5,178	-4,950	13,581	-6,297	**-2,844**
3. Land transport	-2,629	316	7,432	-2,590	**2,529**
4. Maritime transport	-538	101	1,082	-312	**334**
5. Air transport	-1,603	25	5,189	-1,950	**1,661**
6. Auxiliary transport services	-375	515	2,259	-542	**1,857**
7. Post and telecommunications	-71	339	724	348	**1,341**
8. Financial intermediation	-314	-692	7,792	-6,205	**582**
9. Real estate and business activities	-1,115	2,109	6,585	-962	**6,617**
10. Education	-651	-68	3,325	-1,318	**1,287**
11. Health services	-1,222	-181	5,878	-2,541	**1,935**
12. Other services	-976	1,478	3,709	-908	**3,304**
13. Public administration	-2,392	-966	4,087	-1,380	**-651**
Total	**-20,201**	**4,163**	**68,994**	**-27,472**	**25,484**

Figure 7. Total changes in the decomposed terms (Kt)