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The materiality of the immaterial. Services sectors and CO_2 emissions in Uruguay

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Abstract

This paper analyzes the carbon dioxide emissions of the services sectors subsystem of Uruguay in 2004. Services, with the exception of transport, are often considered intangible because of their low level of direct emissions. However, the provision of services requires inputs produced by other sectors, including several highly material-intensive sectors.

Through input–output analysis we investigate the relationship between the services subsystem and the rest of the economy as regards carbon dioxide emissions. This approach allows us to study the importance of the set of services branches as a unit in the economic structure as well as to analyze in detail the relationship between the branches. The results depict that services' direct emissions are the main component, as a consequence of transport-related sectors. However, the pollution that the services subsystem makes the rest of the economy produce is very significant, and it is almost all explained by non-transport-related sectors. This analysis is useful for determining the sectors in which mitigation policies are more effective, and whether they would be better tackled through technical improvements and better practices or through demand policies.

Keywords: input–output analysis, subsystems, carbon dioxide emissions, services.

1. Introduction

Services were wrongly considered intangible and unusable to create value like the industrial sectors by Adam Smith. In modern times, this deficient characterization has been expressed in different ways. Services have been considered non-capital intensive, with low productivity growth and an inability to be economic driving forces because their output can only be sold locally. This leads to them being perceived as "environment-friendly" and even "non-material" activities (with the exception of transport-related sectors) (Gallouj and Djellal, 2010).[1] This idea is supported by the fact that services do not produce material goods and they are not very important direct polluters. Hence, the emission intensities per unit of output of non-transport services are lower than the emission intensities of other sectors of the economy (Suh, 2006). This has led to services industries being widely ignored when designing mitigation policies (Rosenblum et al., 2000; Gadrey, 2010).

However, as Fourcroy et al. (2012) remarked, the provision of services is developed through interactions with customers who are reached through a combination of service operations, conditioning and travel. Each of these elements requires direct energy consumption (and hence pollution), but also requires other sectors to consume raw materials and energy, and to pollute when taking part in these interactions. Gadrey (2010) shows that countries where the services sector accounts for a larger share of the economy consume more energy and have larger ecological footprints than countries where the services sectors are less developed. These arguments contradict the false perception that services sectors are non-material sectors, as shown by several authors (Rosenblum et al., 2000; Suh, 2006; Nansai et al., 2007; Alcántara and Padilla, 2009; and Fourcroy et al., 2012).

The greenhouse gas (GHG) emissions from the Uruguayan productive structure reached 36,773 ktons (in carbon dioxide equivalent units) in 2004.[2] The Uruguayan National Climate Change Response Plan (NCCRP) (MVOTMA, 2010a) exposes the strategic lines of action for GHG mitigation, making reference, in general terms, to improving

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[1] Fourcroy et al. (2012) presented an excellent review of the evolution of the concept of non-materiality of services.

[2] Accounting for CO_2, CH_4 and N_2O. The sectoral allocation of emissions is elaborated by the authors based on DNETEN (2008) and MVOTMA (2010b), following the Eurostat (2009) methodology. An appendix detailing this process is available upon request.

the practices in the primary sectors, transport and waste management, and to improving energy efficiency and reducing energy consumption. Despite carbon dioxide emissions only representing 16.6% of the total Uruguayan GHGs in 2004, it is noticeable that half of them are directly related to the services sectors. The NCCRP mitigation lines of action explicitly consider transport-related sectors as well as improvements in the lighting systems of services branches. They also consider energy efficiency improvements in general terms. In this sense, the decomposition of the services subsystem multipliers will allow the orientation of the design of complementary mitigation policies.

The present paper analyzes the carbon dioxide emissions of the services sector subsystem of Uruguay in 2004. Input–output analysis extended to carbon dioxide emissions helps to determine which kind of policy measures are better and in which sectors mitigation policies will be more effective. We combine two decomposition methodologies. First, we apply the multiplicative decomposition developed by Pyatt and Round (1979) and later applied to interregional multipliers by Miller (1969), Sonis and Hewings (1993) and Dietzenbacher (2002) to analyze the relationship between each subsystem and the rest of the economy. This methodology captures the full circular flow of transactions for production in the economy. Second, we apply additive decomposition to analyze the relationship within the subsystem itself. This allows a more intuitive and easier interpretation of the relationships within the subsystem's sectors. Multiplier decomposition can be interpreted as systems that produce "pollution by means of pollution" (Alcántara, 1995), as an environmentally extended application of Sraffa's (1972) "production of commodities by means of commodities."

The paper is organized as follows: Section 2 presents the methodology; Section 3 provides the empirical results; and the final section concludes.

2. Methodology

Input–output analysis is a tool that has been widely used for measuring structural interdependence since Hirschman (1958). Environmentally extended input–output analysis allows for a more complete understanding of the relationship between the economy and the material flows, which is essential for fully understanding environmental problems and the policy design to solve them (Hoekstra, 2005). Sometimes it is relevant to focus on some specific sectors, and not to analyze the environmental impact of the whole economic system. This allows the study of their relationship with the environment with greater complexity, without losing their linkages with the entire production system (Alcántara, 1995). If we consider a system of industries in which each produces a different commodity as defined in input–output analysis, "such a system can be subdivided into as many parts as there are commodities in its net product, in such a way that each part forms a smaller self-replacing system, the net product of which consists of only one kind of commodity. These parts we shall call 'subsystems'" (Sraffa, 1960, p. 89). Thus, subsystem analysis allows the study of the structure of each of the industries involved in the economic system, while it increases the explanatory power of the traditional approach of key sector analysis, providing a greater level of disaggregation of the linkages between those branches within the subsystem and between the subsystem branches and the rest of the economy (Alcántara and Padilla, 2009; Navarro and Alcántara, 2010).

Subsystem analysis of the relationship between the productive structure and the environment was first proposed by Alcántara (1995), who applied it to sulfur dioxide, nitrogen oxides and volatile organic compound emissions in Spain in 1985 through additive decomposition of the emissions generated by each industry into five components: i) scale; ii) feedback; iii) own; iv) spillover; and v) the spillover of the rest of the economy. Alternative additive decompositions were employed to analyze the environmental impact in water resources pollution in Aragon, Spain, in 1995 by Sánchez-Chóliz and Duarte (2003), carbon dioxide emissions in the services subsystem in Spain in 2000 by Alcántara and Padilla (2009), methane emissions in the agricultural and food industry in Catalonia, Spain, in 2001 by Navarro and Alcántara (2010) and six greenhouse gases in Ireland in 2005 by Llop and Tol (2012). Multiplicative decomposition derived from the Miyazawa (1966, 1968, 1971) multipliers was employed by Firtz et al. (1998) to analyze how the subsystem of non-polluting sectors influenced the emissions of air polluting sectors in the Chicago region through a structural decomposition analysis between 1975 and 2010.

Multiplicative decomposition isolates better the internal interrelationships of the subsystem from those with the rest of the economy than additive decomposition.

Because of this, we employ multiplicative decomposition to disentangle the internal linkages of the services subsystem from its linkages with the rest of the economy. However, the internal component of the services subsystem deserves to be analyzed in greater detail to allow a better understanding of the relationships between the sectors within the subsystem. We decompose these internal relationships through additive decomposition, because it allows a more intuitive interpretation when considering sectors one by one (after isolating the subsystem's internal interrelationships from those with the rest of the economy).

The Leontief model identity, $\boldsymbol{x'} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{y'} = \boldsymbol{L}\boldsymbol{y}'$, denotes the relationship between the total output levels ($\boldsymbol{x'}$) required in an economy to hold a final demand column vector ($\boldsymbol{y'}$) through the inverse Leontief matrix (or matrix of coefficients of direct and indirect requirements per unit of final demand).[3] Matrix $\boldsymbol{A}$ is the Leontief technical coefficients matrix, the elements, a_{ij}, of which depict the weight of how much sector j purchases from sector i in relation to the total sector j production. To isolate the effects of subsystem s this model can be rewritten in a partitioned way as:

$$(1) \qquad \begin{pmatrix} \boldsymbol{x}^{s\prime} \\ \boldsymbol{x}^{r\prime} \end{pmatrix} = \left(\begin{bmatrix} \boldsymbol{I}_{s\times s} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{I}_{r\times r} \end{bmatrix} - \begin{bmatrix} \boldsymbol{A}_{ss} & \boldsymbol{A}_{sr} \\ \boldsymbol{A}_{rs} & \boldsymbol{A}_{rr} \end{bmatrix} \right)^{-1} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix} = \begin{bmatrix} \boldsymbol{L}_{ss} & \boldsymbol{L}_{sr} \\ \boldsymbol{L}_{rs} & \boldsymbol{L}_{rr} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix}$$

Following Pyatt and Round (1979), Round (1985, 2001), Sonis and Hewings (1993) and Dietzenbacher (2002), the inverse Leontief matrix, $\boldsymbol{L}$, can be decomposed as follows:

$$(2) \qquad \begin{pmatrix} \boldsymbol{x}^{s\prime} \\ \boldsymbol{x}^{r\prime} \end{pmatrix} = \begin{bmatrix} \boldsymbol{F}_s & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_r \end{bmatrix} \times \begin{bmatrix} \boldsymbol{I}_{s\times s} & \boldsymbol{S}_{sr} \\ \boldsymbol{S}_{rs} & \boldsymbol{I}_{r\times r} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{M}_s & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix}$$

$$= \begin{bmatrix} \boldsymbol{F}_s\boldsymbol{M}_s & \boldsymbol{F}_s\boldsymbol{S}_{sr}\boldsymbol{M}_r \\ \boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s & \boldsymbol{F}_r\boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix}$$

where:

$\boldsymbol{M}_s = (\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}$ and $\boldsymbol{M}_r = (\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}$

$\boldsymbol{S}_{sr} = (\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}\boldsymbol{A}_{sr}$ and $\boldsymbol{S}_{rs} = (\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}\boldsymbol{A}_{rs}$

$\boldsymbol{F}_s = [\boldsymbol{I} - (\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}\boldsymbol{A}_{sr}(\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}\boldsymbol{A}_{rs}]^{-1} = [\boldsymbol{I} - \boldsymbol{S}_{sr}\boldsymbol{S}_{rs}]^{-1}$

[3] In this paper, elements in **bold** denote vectors and matrices (lower case and upper case, respectively), while the scalars are expressed in plain text. In turn, the ^ symbol over a vector element refers to a diagonal matrix composed of the specified vector.

$$\boldsymbol{F}_r = [\boldsymbol{I} - (\boldsymbol{I} - \boldsymbol{A}_{rr})^{-1}\boldsymbol{A}_{rs}(\boldsymbol{I} - \boldsymbol{A}_{ss})^{-1}\boldsymbol{A}_{sr}]^{-1} = [\boldsymbol{I} - \boldsymbol{S}_{rs}\boldsymbol{S}_{sr}]^{-1}$$

The production needed to obtain the total output of subsystem s can be isolated assuming $\boldsymbol{y}^r = \boldsymbol{0}$, such that:

(3) $$\begin{pmatrix} \boldsymbol{x}_s^{s\,\prime} \\ \boldsymbol{x}_s^{r\,\prime} \end{pmatrix} = \begin{bmatrix} \boldsymbol{L}_{ss} & \boldsymbol{L}_{sr} \\ \boldsymbol{L}_{rs} & \boldsymbol{L}_{rr} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\,\prime} \\ \boldsymbol{0} \end{pmatrix} = \begin{bmatrix} \boldsymbol{F}_s\boldsymbol{M}_s & \boldsymbol{F}_s\boldsymbol{S}_{sr}\boldsymbol{M}_r \\ \boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s & \boldsymbol{F}_r\boldsymbol{M}_r \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\,\prime} \\ \boldsymbol{0} \end{pmatrix}$$

where $\boldsymbol{x}_s^s$ is the production of subsystem s to satisfy its final demand and $\boldsymbol{x}_s^r$ is the production of the rest of the economy to be employed as input by subsystem s. Premultiplying (3) by $\boldsymbol{u}$, a summation row vector, the total production of the economy that is needed for the final demand of subsystem s is obtained:

(4) $$\boldsymbol{u}_{1\times n} \begin{pmatrix} \boldsymbol{x}_s^{s\,\prime} \\ \boldsymbol{x}_s^{r\,\prime} \end{pmatrix} = \boldsymbol{u}_{1\times s}\boldsymbol{L}_{ss}\boldsymbol{y}^{s\,\prime} + \boldsymbol{u}_{1\times r}\boldsymbol{L}_{rs}\boldsymbol{y}^{s\,\prime} = \boldsymbol{u}_{1\times s}\boldsymbol{F}_s\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime} + \boldsymbol{u}_{1\times r}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}$$

where the first term accounts for both the internal transactions of subsystem s to satisfy its final demand and a *feedback* component, which accounts for the sales of subsystem s to the rest of the economy that are employed for providing inputs to the sectors of subsystem s. The second term accounts for those sales from the rest of the economy employed by subsystem s as inputs to satisfy its final demand. The first component can be decomposed, adding and subtracting $\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}$, such that:

(5) $$\boldsymbol{u}_{1\times n} \begin{pmatrix} \boldsymbol{x}_s^{s\,\prime} \\ \boldsymbol{x}_s^{r\,\prime} \end{pmatrix} = \boldsymbol{u}_{1\times s}\boldsymbol{F}_s\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime} + \boldsymbol{u}_{1\times s}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime} - \boldsymbol{u}_{1\times s}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime} + \boldsymbol{u}_{r\times 1}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}$$
$$= \underbrace{\boldsymbol{u}_{1\times s}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{internal\ component} + \underbrace{\boldsymbol{u}_{1\times s}[\boldsymbol{F}_s - \boldsymbol{I}]\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{feedback\ component} + \underbrace{\boldsymbol{u}_{1\times r}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{spillover\ component}$$

The expression above decomposes the total production that is needed to fulfill the total final demand of subsystem s. It is also relevant to split those components between the sectors of subsystem s. For this purpose, each component can be rewritten, diagonalizing the last vector, such that:

Internal component:

(6) $\boldsymbol{u}_{1\times s}\boldsymbol{M}_s\hat{\boldsymbol{y}}^s$

where $\boldsymbol{M}_s\hat{\boldsymbol{y}}^s$ depicts the total production of subsystem *s* (both final output and intermediate inputs) to satisfy its final demand. However, the internal component can be split to shed light on the relationships within the subsystem. For this purpose, it is useful to decompose the internal component following additive decomposition. This will allow us to distinguish between: a) the production of a sector of subsystem *s* used to satisfy its own final demand (*internal scale component*); b) the production of a sector of *s* that is purchased as input by itself to satisfy its final demand (*internal own component*); c) the production of a sector of subsystem *s* purchased as input by other sectors of the same subsystem and employed to produce inputs bought by this sector to satisfy its final demand (*internal feedback component*); and d) inputs that a sector of subsystem *s* demands from other sectors of the same subsystem to satisfy its final demand (*internal spillover component*).

For this, matrix $\boldsymbol{M}_s$ can be written as $\boldsymbol{M}_s = \boldsymbol{M}_s^D + \boldsymbol{M}_s^O$, where $\boldsymbol{M}_s^D$ is a diagonal *s*x*s* matrix that contains the main diagonal of matrix $\boldsymbol{M}_s$, while matrix $\boldsymbol{M}_s^O$ is equal to matrix $\boldsymbol{M}_s$, but with null values in its main diagonal. The technical coefficients matrix of subsystem *s* can be rewritten in the same way, such that $\boldsymbol{A}_{ss} = \boldsymbol{A}_{ss}^D + \boldsymbol{A}_{ss}^O$. From above, $\boldsymbol{M}_s$ can be expressed as $\boldsymbol{M}_s = \boldsymbol{A}_{ss}^D\boldsymbol{M}_s^D + \boldsymbol{A}_{ss}^O\boldsymbol{M}_s + \boldsymbol{A}_{ss}^D\boldsymbol{M}_s^O + \boldsymbol{I}$.[4] Equation (6) can be written as:

(7) $$\boldsymbol{u}_{s\times 1}\boldsymbol{M}_s\widehat{\boldsymbol{y}^s} = \underbrace{\boldsymbol{u}_{s\times 1}\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^D\hat{\boldsymbol{y}}^s}_{\substack{internal\ own\\ component}} + \underbrace{\boldsymbol{u}_{s\times 1}\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^O\hat{\boldsymbol{y}}^s}_{\substack{internal\ feedback\\ component}} + \underbrace{\boldsymbol{u}_{s\times 1}\boldsymbol{A}_{ss}\boldsymbol{M}_s^{\boldsymbol{O}}\hat{\boldsymbol{y}}^s}_{\substack{internal\ spillover\\ component}} + \underbrace{\boldsymbol{u'}_{s\times 1}\hat{\boldsymbol{y}}^s}_{\substack{internal\ scale\\ component}}$$

Feedback component:

(8) $\boldsymbol{u}_{s\times 1}[\boldsymbol{F}_s - \boldsymbol{I}]\boldsymbol{M}_s\hat{\boldsymbol{y}}^s$

is the production of the sectors of subsystem *s* used as inputs by sectors from outside the subsystem, but which are used by them to provide inputs to the subsystem sectors.

Spillover component:

(9) $\boldsymbol{u}_{r\times 1}\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\hat{\boldsymbol{y}}^s$

[4] $\boldsymbol{M}_s = [\boldsymbol{M}_s - \boldsymbol{I}] + \boldsymbol{I} = \boldsymbol{A}_{ss}\boldsymbol{M}_s + \boldsymbol{I} = (\boldsymbol{A}_{ss}^D + \boldsymbol{A}_{ss}^O)(\boldsymbol{M}_s^D + \boldsymbol{M}_s^O) + \boldsymbol{I} = \boldsymbol{A}_{ss}^D\boldsymbol{M}_s^D + \boldsymbol{A}_{ss}^O\boldsymbol{M}_s^D + \boldsymbol{A}_{ss}\boldsymbol{M}_s^O + \boldsymbol{I}$

depicts the production from sectors that do not belong to subsystem *s* providing inputs to satisfy its final demand.

The model above can be easily extended to any environmental dimension to take into account the environmental impact. We define $\boldsymbol{c}_{nx1}{}' = \begin{pmatrix} c_1 \\ \vdots \\ c_n \end{pmatrix}$, a vector of coefficients that relates every sector with a particular environmental dimension (either resource use or pollution), such that $\boldsymbol{c}'\boldsymbol{x} = E$, where $\boldsymbol{x}$ is the vector of sector output and E is a scalar that denotes the total resource use or pollution generation. Henceforth, $\boldsymbol{c}$ is defined as the carbon dioxide emissions' intensity vector. In this way, the direct emissions coefficient of sector *j* can be defined as $c_j = {}^{e_j}/_{x_j}$, where e_j indicates sector *j*'s direct emissions. The emissions coefficients vector can be expressed in a partitioned way, as before, such that $\boldsymbol{c}_{nx1}{}' = \begin{pmatrix} \boldsymbol{c}^{s\prime} \\ \boldsymbol{c}^{r\prime} \end{pmatrix}$, where $\boldsymbol{c}^{s}$ are the coefficients of the direct emission of the sectors of subsystem *s*. Premultiplying (1) by a diagonal matrix constructed from vector $\boldsymbol{c}$, the model can be transformed as:

$$(10)\quad \begin{aligned} \boldsymbol{e}' &= \hat{\boldsymbol{c}}\boldsymbol{x} = \hat{\boldsymbol{c}}\boldsymbol{L}\boldsymbol{y}' \\ &= \begin{pmatrix} \widehat{\boldsymbol{c}^{s}} & \boldsymbol{0} \\ \boldsymbol{0} & \widehat{\boldsymbol{c}^{r}} \end{pmatrix} \begin{bmatrix} \boldsymbol{L}_{ss} & \boldsymbol{L}_{sr} \\ \boldsymbol{L}_{rs} & \boldsymbol{L}_{rr} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix} \\ &= \begin{pmatrix} \widehat{\boldsymbol{c}^{s}} & \boldsymbol{0} \\ \boldsymbol{0} & \widehat{\boldsymbol{c}^{r}} \end{pmatrix} \begin{bmatrix} \boldsymbol{F}_{s} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{F}_{r} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{I} & \boldsymbol{S}_{sr} \\ \boldsymbol{S}_{rs} & \boldsymbol{I} \end{bmatrix} \times \begin{bmatrix} \boldsymbol{M}_{s} & \boldsymbol{0} \\ \boldsymbol{0} & \boldsymbol{M}_{r} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix} \\ &= \begin{pmatrix} \widehat{\boldsymbol{c}^{s}} & \boldsymbol{0} \\ \boldsymbol{0} & \widehat{\boldsymbol{c}^{r}} \end{pmatrix} \begin{bmatrix} \boldsymbol{F}_{s}\boldsymbol{M}_{s} & \boldsymbol{F}_{s}\boldsymbol{S}_{sr}\boldsymbol{M}_{r} \\ \boldsymbol{F}_{r}\boldsymbol{S}_{rs}\boldsymbol{M}_{s} & \boldsymbol{F}_{r}\boldsymbol{M}_{r} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{y}^{r\prime} \end{pmatrix} \end{aligned}$$

where $\boldsymbol{e}_{n\times 1}{}'$ is a column vector, the elements of which are $e_j\ \forall\, j = 1, \dots, n$. Again, to analyze the role of subsystem *s* in the total emissions, $\boldsymbol{y}^{r} = 0$ is assumed, such that:

$$(11)\quad \begin{bmatrix} \boldsymbol{e}_{s}^{s\prime} \\ \boldsymbol{e}_{r}^{s\prime} \end{bmatrix} = \begin{bmatrix} \widehat{\boldsymbol{c}^{s}} & \boldsymbol{0} \\ \boldsymbol{0} & \widehat{\boldsymbol{c}^{r}} \end{bmatrix} \begin{bmatrix} \boldsymbol{F}_{s}\boldsymbol{M}_{s} & \boldsymbol{F}_{s}\boldsymbol{S}_{sr}\boldsymbol{M}_{r} \\ \boldsymbol{F}_{r}\boldsymbol{S}_{rs}\boldsymbol{M}_{s} & \boldsymbol{F}_{r}\boldsymbol{M}_{r} \end{bmatrix} \begin{pmatrix} \boldsymbol{y}^{s\prime} \\ \boldsymbol{0} \end{pmatrix}$$

where $\boldsymbol{e}_{s}^{s}$ are those emissions coming from the production processes of subsystem *s* to satisfy its own final demand and $\boldsymbol{e}_{r}^{s}$ is the pollution from the rest of the sectors during their production processes to provide subsystem *s* with the inputs it needs to satisfy its final demand. Similar to equation (5), by premultiplying (1) by a unitary vector $\boldsymbol{u}_{nx1}$, we obtain the total emissions of subsystem *s* (E^s):

(12) $$E^s = \boldsymbol{c}^s\boldsymbol{F}_s\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime} + \boldsymbol{c}^r\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\prime} = \underbrace{\boldsymbol{c}^s\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{internal\ component} + \underbrace{\boldsymbol{c}^s[\boldsymbol{F}_s - \boldsymbol{I}]\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{feedback\ component} + \underbrace{\boldsymbol{c}^r\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\boldsymbol{y}^{s\,\prime}}_{spillover\ component}$$

In the same way as in equations (6) to (9), each component can be split for each sector of subsystem *s*.

(13) $\boldsymbol{\mu}_s^{internal} = \boldsymbol{c}^s\boldsymbol{M}_s\widehat{\boldsymbol{y}}^s$

depicts the contribution of each subsystem sector to the subsystem internal component. The internal component shows both the emissions produced by subsystem *s* when producing products to satisfy its own final demand directly and the emissions when producing inputs demanded by itself, also to satisfy its own final demand.

Again, as for equation (7), equation (13) can be split to distinguish between: a) those emissions that a sector of subsystem *s* directly produces to satisfy its final demand (*internal scale component*); b) the pollution of a sector of subsystem *s* when producing inputs purchased by itself (*internal own component*); c) the pollution generated by a sector of subsystem *s* when producing inputs that are used by other sectors of the same subsystem to provide inputs to it (*internal feedback component*); and d) the emissions that a sector from subsystem *s* makes other sectors of the same subsystem generate in their productive processes to provide inputs for its final demand (*internal spillover component*).

(13a) $\boldsymbol{\mu}_s^{internal-scale} = \boldsymbol{c}^s\widehat{\boldsymbol{y}}^s$

(13b) $\boldsymbol{\mu}_s^{internal-own} = \boldsymbol{c}^s\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^D\widehat{\boldsymbol{y}}^s$

(13c) $\boldsymbol{\mu}_s^{internal-feedback} = \boldsymbol{c}^s\boldsymbol{A}_{ss}^D\boldsymbol{M}_s^O\widehat{\boldsymbol{y}}^s$

(13d) $\boldsymbol{\mu}_s^{internal-spillover} = \boldsymbol{c}^s\boldsymbol{A}_{ss}\boldsymbol{M}_s^O\widehat{\boldsymbol{y}}^s$

In addition,

$$(14) \quad \boldsymbol{\mu}_s^{feedback} = \boldsymbol{c}^s(\boldsymbol{F}_s - \boldsymbol{I})\, \boldsymbol{M}_s\hat{\boldsymbol{y}}^s$$

shows the contribution of each subsystem sector to the subsystem feedback component. It depicts those emissions produced by the sectors of subsystem *s* to provide inputs to sectors outside the subsystem, but which are used by them to provide inputs to subsystem sectors. Finally,

$$(15) \quad \boldsymbol{\mu}_s^{spillover} = \boldsymbol{c}^r\boldsymbol{F}_r\boldsymbol{S}_{rs}\boldsymbol{M}_s\hat{\boldsymbol{y}}^s$$

depicts the contribution of each subsystem sector to the subsystem spillover component. The spillover component accounts for those emissions produced by sectors not belonging to subsystem *s* to provide inputs to sectors of subsystem *s* to satisfy their final demand.

3. The services subsystem and carbon dioxide emissions in Uruguay

The analysis is conducted using the 2005 Uruguayan input–output matrix constructed by Terra et al. (2009) in the benchmark of a Red Mercosur–Food and Agricultural Organization (FAO) agreement for technical assistance to the Agriculture, Livestock and Fishing Ministry. It is split into 56 activities at basic prices. We constructed the carbon dioxide emissions accounts from the 2004 greenhouse gas inventory that the Ministry of Housing, Land Use Planning and Environment reports to the Intergovernmental Panel for Climate Change (MVOTMA, 2010a). The greenhouse gas inventory classifies emissions in reference to their processes of origin. To allocate the sectoral emissions we follow the Eurostat (2009) methodology, and we employ secondary sources like the reports of the National Energy and Nuclear Technology Direction (DNETN, 2008), which detail the structure of net and used energy consumption for the year 2006.[5]

The total carbon dioxide emissions in Uruguay in 2004 reached 8,675 ktons, 70% of which came from the productive sectors (MVOTMA, 2010b).[6] The services subsystem

[5] A methodological annex detailing the sectoral allocation of emissions is available upon request.
[6] It considers international bunkers and biomass burning CO_2 emissions.

consists of 13 sectors that represented 52.5% of the Uruguayan total output in 2005.[7] Its direct emissions reached 2,783.7 ktons, while the total (direct plus indirect) emissions according to input–output analysis were 2,862 ktons in 2004 (45.7% and 46.9% of the total CO_2 emissions, respectively) (Table 1).

[Table 1]

The direct and total emissions of the services subsystem are quite similar in absolute terms. On the one hand, despite the sectors Land transport; transport via pipelines (46); and Water and air transport (47) being the two main contributors to the subsystem's direct emissions, their contribution to the subsystem's total emissions is significantly smaller. On the other hand, the contribution to the total emissions significantly rises in relation to direct emissions for Motor vehicles and oil retail trade (44); Hotels and restaurants (45); and Public administration and defense; compulsory social security (52). For the other sectors the variation is very small. Because of the trade-off between direct and indirect emissions of the contribution of these sectors it is worth decomposing the total emissions in order to be better able to distinguish the best channels for mitigation policies.

Table 2 shows the decomposition of the services subsystem multipliers. The internal component explains most carbon dioxide emissions of this subsystem (77.8%). The significance of the internal component is mainly explained by the internal scale component (63.4% of the total emissions of the services subsystem). These emissions are mainly produced by the two transport-related sectors (46 and 47), which are the main direct polluters. Both sectors allocate more than 60% of their production to the final demand. In this way, technological improvement and best practices are effective policies to mitigate the carbon dioxide emissions of these sectors. This point shows the importance of the reduction of energy consumption in the transport sectors, which is identified as a priority line of action in the NCCRP.

[7] In the existing literature, services activities are defined through both a positive and a residual definition. For the residual definition services are all the activities that are not manufacturing or agricultural activities, while for the positive definition services are branches that meet specific characteristics that distinguish them from other economic activities (Fourcroy et al., 2012). For the Uruguayan case, and the level of aggregation of the input–output matrix employed, the two perspectives are highly coincident.

[Table 2]

Less relevant, but still significant, is the weight of the internal spillover component (11.7% of the total emissions of the services subsystem). The main contributor to this component is the Motor vehicles and oil retail trade sector (44) (58.2%), while the rest of the emissions are spread among the other sectors. This is because it pulls the transport-related sectors (46 and 47) to pollute as a consequence of the inputs that sector 44 demands from them. In this way, demand policies in this sector can be useful for mitigating carbon dioxide emissions.

Also very significant is the spillover component. It represents 19.7% of the overall emissions of the services subsystem and 9.3% of the emissions of the whole productive system. This component is very important because it depicts the emissions that the subsystem makes the rest of the economy to produce to meet its final demand. That is, this component is the one that sheds light on the indirect emissions not accounted for when the services are considered to be non-material. This result clearly shows that the services demand is also based on the materiality of the rest of the economy. Additionally, the services sectors not related to transport activities account for 90% of the subsystem spillover component. This is different from the internal own component whereby transport activities share almost all of the emissions. The significance of these sectors for the spillover component is due to their demand from the electricity, gas and water supply sector (42). Thus, this analysis helps to identify where energy efficiency measures, as identified in the NCCRP priority action lines, are more effective. The relevance of the spillover component is in line with the analysis of Alcántara and Padilla (2009) for the Spanish economy. Finally, the feedback component is almost negligible.

4. Conclusions

In the present paper, we analyze the carbon dioxide emissions of the services sectors subsystem of Uruguay in 2004. We combine multiplicative decomposition to analyze the relationship of the subsystem with the rest of the economy with additive decomposition for the study of the linkages within it. This approach allows us to study the significance of the subsystem as a whole in the economic structure as well as to analyze in detail the relationship between each of the subsystem’s branches.

Services sectors have been considered as “non-material” because they are not extremely important direct polluters and have lower emission intensities per unit of output than other sectors of the economy (except in the case of transport sectors). However, service provision can indirectly impact on other sectors’ pollution, because their production is needed for service provision. Rosenblum et al. (2000) list four kinds of measures that can act on services sectors to influence their environmental performance: influencing suppliers to provide more environmentally conscious products and services, improving their energy efficiency and cutting business travel, consumers’ education programs about the relative merits of the different products that are offered and substituting more environmentally beneficial services or activities to reduce the resource use by the final demand. Environmentally extended input–output analysis for the services subsystem allows us to identify the relevance of services as indirect polluters and which kinds of mitigation policies would be more effective, in addition to the implementation of technical improvements and better practices, which would be effective in direct polluter sectors.

The results show that both the internal component and the spillover to the rest of the economy are significant. The emissions of the internal component are mainly explained by the internal scale component, largely produced by transport-related services, which are also the main direct polluters. However, the internal spillover component of the services subsystem is also important, mainly because Motor vehicles and oil retail trade (44) pulls the transport-related sectors to pollute.

Finally, the spillover component represents 19.7% of the overall carbon dioxide emissions of the services subsystem and 9.3% of the emissions of the whole productive system. This component is very important because it accounts for the indirect pollution that the services sectors make the rest of the economy produce to satisfy their final demand. This component is spread among many sectors of the services subsystem. Also, 90% of this component is caused by non-transport services. This is explained mainly because these sectors demand inputs to the Electricity, gas and water supply (42) sector, which does not belong to the services subsystem.

The above results mean that the pollution of the services subsystem is important not only because of its internal transactions, but also because it pulls other sectors of the economy to pollute. This refutes the non-material perception of services sectors, in line with Rosenblum (2000), Suh (2006), Nansai et al. (2007), Alcántara and Padilla (2009), Gadrey (2010) and Fourcroy et al. (2012).

It is worth noting that technical improvements and best practices in reference to energy consumption are plausible ways of implementing demand policies in the services subsystem. However, services demand policies, like labeling and certification to give information to the final consumers or encouraging the substitution of cleaner inputs, can also be effective policies. However, it must be considered that to achieve an accurate design for a mitigation program, the rebound effects should be adequately taken into account. The above analysis is a useful guideline for the efficient design of specific measures aligned with the NCCRP priority lines of action. It allows the determination of both the sectors in which mitigation policies are more effective and the kinds of measures that are more appropriate in each case.

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Table 1: Services subsystem sectors, output and direct and indirect CO_2 emissions

Sector	Name	Output US$:	% Output	Direct CO_2 Ktons	% Direct CO_2	Total CO_2 Ktons	% Total CO_2
44	Motor vehicles and oil retail trade	3,096.7	10.6%	14.8	0.2%	317.6	5.2%
45	Hotels and restaurants	867.3	3.0%	26.3	0.4%	161.9	2.7%
46	Land transport; transport via pipelines	957.5	3.3%	1261.2	20.7%	866.3	14.2%
47	Water and air transport	875.3	3.0%	1371.5	22.5%	962.9	15.8%
48	Post and telecommunications	777.8	2.7%	0.0	0.0%	35.4	0.6%
49	Financial intermediation	1,243.7	4.3%	1.5	0.0%	16.3	0.3%
50	Real estate activities	2,164.6	7.4%	0.0	0.0%	65.5	1.1%
51	Renting of machinery and equipment	941.1	3.2%	0.0	0.0%	22.6	0.4%
52	Public administration and defense; compulsory social security	1,238.2	4.2%	44.7	0.7%	159.2	2.6%
53	Education	722.0	2.5%	5.8	0.1%	51.5	0.8%
54	Health and social work	1,465.6	5.0%	16.9	0.3%	107.1	1.8%
55	Sewage and refuse disposal	795.0	2.7%	40.9	0.7%	96.0	1.6%
56	Private households with employed persons	192.3	0.7%	0.0	0.0%	0.0	0.0%
Total services subsystem		**15,337**	**52.5%**	**2783.7**	**45.7%**	**2,862**	**46.9%**
Total		**29,229**	**100%**	**6,097**	**100%**	**6,097**	**100%**

Source: own elaboration based in DNTEN (2008), Terra et al. (2009), and MVOTMA (2010a)

Table 2: Decomposition of the CO_2 emissions of the services subsystem

Sector	Internal scale component	%	Internal own component	%	Internal feedback component	%	Internal spillover component	%	Feedback component	%	Spillover component	%	Total CO_2 Ktons	% Total CO_2 serv.
44	10.5	0.6%	0.5	0.7%	5.7	46.7%	194.0	58.2%	11.4	16.0%	95.5	16.9%	317.6	11.1%
45	23.9	1.3%	0.0	0.1%	1.2	9.9%	23.8	7.1%	17.1	23.9%	95.8	17.0%	161.9	5.7%
46	766.4	42.2%	44.5	69.1%	0.1	0.9%	7.2	2.2%	3.1	4.4%	45.0	8.0%	866.3	30.3%
47	921.9	50.8%	15.7	24.4%	0.4	3.7%	8.5	2.6%	1.9	2.7%	14.4	2.6%	962.9	33.6%
48	0.0	0.0%	0.0	0.0%	0.9	7.2%	20.2	6.0%	1.6	2.2%	12.8	2.3%	35.4	1.2%
49	0.6	0.0%	0.1	0.1%	0.3	2.4%	5.6	1.7%	1.0	1.4%	8.7	1.5%	16.3	0.6%
50	0.0	0.0%	0.0	0.0%	0.3	2.5%	5.9	1.8%	7.8	10.8%	51.5	9.1%	65.5	2.3%
51	0.0	0.0%	0.0	0.0%	0.3	2.8%	7.4	2.2%	1.6	2.3%	13.3	2.4%	22.6	0.8%
52	41.7	2.3%	0.0	0.0%	1.1	8.8%	21.8	6.5%	6.0	8.4%	88.6	15.7%	159.2	5.6%
53	5.7	0.3%	0.0	0.0%	0.2	1.9%	5.0	1.5%	2.9	4.0%	37.6	6.7%	51.5	1.8%
54	14.4	0.8%	2.1	3.3%	0.9	7.5%	18.6	5.6%	11.3	15.8%	59.8	10.6%	107.1	3.7%
55	30.7	1.7%	1.5	2.3%	0.7	5.7%	15.5	4.6%	5.8	8.1%	41.9	7.4%	96.0	3.4%
56	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Total services subsystem	**1,815.8**	**63.4%**	**64.4**	**2.2%**	**12.2**	**0.4%**	**333.5**	**11.7%**	**71.6**	**2.5%**	**564.9**	**19.7%**	**2,862**	**100%**
% of total CO_2 emissions	**29.8%**		**1.1%**		**0.2%**		**5.5%**		**1.2%**		**9.3%**		**46.9%**	

Source: own elaboration based in DNTEN (2008), Terra et al. (2009), and MVOTMA (2010a)

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