ANALYSING WATER POLLUTION BY WAY OF VERTICALLY INTEGRATED COEFFICIENTS. AN APPLICATION TO THE ARAGONESE ECONOMY (SPAIN)

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ABSTRACT

In this paper we adopt Pasinetti's approach of vertically integrated sectors in order to disaggregate water pollution into its most significant components. Vertical integration allows us to obtain five components (and five measurement indexes) corresponding to each sector and each type of pollution. These indexes overcome some of the deficiencies of the traditional Rasmussen-type coefficients.

The empirical application is carried out by reference to the Spanish region of Aragón, which lies in North-eastern Spain, for five polluting factors, namely: Water returns, Biological Demand Oxygen at five days (BDO5) , Suspended Solids (SS), Nitrates and Phosphates.

Keywords: Input-output, pollution, backward linkage, forward linkage, vertical integration.

JEL CLASSIFICATIONS: D57, Q25, C67

1. Introduction

The potential of input-output analysis for studying the linkages between the sectors of an economy, and for determining the role played by each sector, is widely recognised. The study of sectoral linkages is particularly relevant when considering environmental pollution, in that any anti-pollution measure must take into account its effects on all the sectors of the economy.

In all multisectoral models of the input-output type, the polluting character of a sector can be determined by reference to the purchases (of pollution) that each sector makes in the economy, and to the sales (of pollution) that this sector itself makes. The problem is how to clearly describe these pollution transactions and to determine precisely which sectors are relevant as purchasers and sellers.

Against this background, in this paper we defend two central arguments. First, that the Pasinetti vertical integration methodology is a powerful framework within which to study the network of relations that link the sectors of an economy from the point of view of pollution. Secondly, that this methodology allows us to obtain indexes or coefficients which are an improvement on those traditionally used to define the *key sector*, the *backward linkage sector* and the *forward linkage sector*, when we wish to apply these in order to analyse the pollution of a given economy.

The rest of the paper is organised as follows. In Section 2 we review some of the indexes that have been most habitually used to measure the degree of interdependence between sectors. In Section 3 we present the vertical integration methodology applied to the case in which we have pollution as an input of production. Using the Passineti matrix of vertically integrated coefficients, we disaggregate pollution into five components. The vertically integrated indexes that are obtained from the dissagregation are presented in section 4. In Section 5, we illustrate the capacity of the proposed methodology by applying it to a particular economy, namely that of Aragon, one of the seventeen autonomous regions into which Spain is divided. Section 6 closes the paper with a review of the main conclusions.

2. Background

In what follows x_{ij} represents the sales of sector *i* to *j*, x_i is the output of i, $\mathbf{x} = (x_i)$ the output vector, $\mathbf{X} = (x_{ij})$ the matrix of intersectoral sales, $\mathbf{A} = (a_{ij}) = (x_{ij}/x_j)$ the matrix of input coefficients, $(\mathbf{I}-\mathbf{A})^{-1} = (\alpha_{ij})$ the Leontief inverse and, finally, $\mathbf{y} = (y_i)$ the vector of final demands. The symbol ^ indicates a diagonal matrix; for example $\hat{\mathbf{x}}$ is the diagonal matrix formed by the elements of **x** .

The study of sectoral relations and dependence has generated an abundant literature in the field of input-output analysis. Here, we can cite the works of Chenery and Watanabe (1958), Rasmussen (1958), Yan and Ames (1965), Schultz (1977) or, more recently, those of Basu and Johnson (1985) or Szyrmer (1992), amongst others. The literature also offers two groups of proposals on how the intersectoral linkage should be measured. The first is based on the analysis of the direct relations between sectors; that is to say, on the study of the elements of the matrix **X** and of the matrixes of technical coefficients **A** and of distribution coefficients $\mathbf{B} = \hat{\mathbf{x}}^{-1}\mathbf{A}\hat{\mathbf{x}}$. The second approaches the question by studying the Leontief inverse $(\mathbf{I}-\mathbf{A})^{-1}$, or the Ghosh inverse $(\mathbf{I}-\mathbf{B})^{-1}$; that is to say, concentrating on both the direct and indirect relations.

Chenery and Watanabe (1958) were the first to systemise the measurements of intersectoral linkage and to establish a classification of sectors by reference to their character of sellers and purchasers. These authors defined two indexes which related the total purchases and sales of a sector with its production,

u_j = **Error!** and w_i = **Error!**

and further established a classification of sectors according to whether these indexes were smaller or larger than the sectoral average, that is to say, that m_u = **Error!** and m_w = **Error!** . This classification can be seen in Table 1.

(Table 1 about here)

One of the main criticisms that has been made of these types of indexes is that they do not take into account the indirect relations of the sector, which can be equally, or even more significant than the direct relations. Further, the final character of the production of the sector is not determined by the weight of the final demand, but rather by the sales character.

The second group of proposals has obtained the sectoral dependency indexes on the basis of the information provided by the Leontief inverse (and, more recently, by the Ghosh inverse for the forward linkage indexes). The elements of the main diagonal, the α_{ii} , have been called the "internal effect"; the sums by columns of the elements of the inverse, $\Sigma;^{n};_{i=1}\alpha_{ij}$, have been called the backward linkage coefficients or simple output multipliers; and, finally, the sums by rows, $\Sigma;^{n};_{j=1}\alpha_{ij}$, are the forward linkage coefficients or input multipliers. An important work in this line is that of Rasmussen (1956) who, using the sums by rows and columns of the Leontief inverse as a starting point, proposed a way to detect *key sectors* or leaders in the economy. For Rasmussen a key sector is that which purchases and sells at a level that is relatively above the average. This author defines the indexes

U_j = **Error!** , W_i = **Error!**

With these, Rasmussen classifies the sectors of the economy into four groups, namely: *key sectors*, *backward linkage sectors*, *forward linkage sectors* and *non significant sectors*, which are set out in Table 2.

(Table 2 about here)

However, indexes of the Rasmussen-type, despite their widespread use in the literature, have themselves been the subject of criticism for a variety of reasons. First, as Rasmussen himself indicated, the classification criteria are too generic and should be completed with others that are more closely linked to the reality being considered. Secondly, given that they are simple ratios, they do not enlighten us on the concentration of the purchases and/or sales. Thirdly, they tell us almost nothing on the division between intersectoral and final demand, and are also independent of the composition of the final demand. Therefore, in order to obtain a better description of the purchases and sales of inputs in the economy, it is necessary to complete the information that these indicators supply with other indexes.

Finally, in these indexes, the self-consumption obscures the forward and backward linkage effects that a sector has over the other sectors of the economy, given that the purchases and sales to themselves could be very relevant. This has led to a definition of Rasmussen-type net indexes in the following form:

U_j;¯; = **Error!** , **Error!** = **Error!** ,

with the first measuring the net backward linkage and the second the net forward linkage.

Rasmussen-type indexes, which incorporate measures of the direct and indirect linkage have been preferred by the input-output literature when studying environmental effects. Thus, Leontief and Ford (1972) studied the impact of the American productive structure on atmospheric pollution, basing their work on such indexes. Similarly, Proops, Faber and Wagenhals (1993) also employed indexes derived form the inverses to study the differences in the productive structures of the United Kingdom and Germany and their effects over CO_2 emissions. On the basis of a Rasmussen-type approach, Pajuelo (1980) characterised the atmospheric pollution of the Spanish economy, while Alcántara (1995) updated this for the 1990 Spanish tables. For these latter authors, if c_{kj} is the *k*-pollution embodied directly into the production of one unit of good *j*, then the Rasmussen-type indexes applied to the *k*-pollution will be:

U_{kj} = **Error!** , W_{ki} = **Error!**

U_{kj};¯; = **Error!** , **Error!** = **Error!** .

These indexes have the same interpretation as those of Rasmussen. However, the difference is that whilst quantities m_i of a good *i* appear in the traditional indexes, we now have $c_{ki}\, m_i$, which is the pollution directly generated when producing m_i in sector *i*. As a result, U_{kj} and U_{kj};¯; offer us a relative measure of how much pollution is transfered to sector j through its purchases of inputs when the final demand of good *j* is increased in one unit. Similarly, W_{ki} and W_{ki};¯; are a relative measurement of the polluting forward linkages. They measure the transfers of pollution associated with the sales of goods of sector *i*. U_{kj};¯; and W_{ki};¯; are the net indexes.

However, criticisms similar to those made of the original indexes can also be levelled at these Rasmussen-type indexes of the *k*-pollution. Thus, it is argued that they are simple ratios which are not weighted neither by the production or the demand, and do not depend on the structure of this. Furthermore, the non-net indexes obscure the polluting backward and forward linkages.

3. An application of the vertical integration methodology

The analysis that we present in this Section is an attempt to overcome the difficulties described in Section 2 through the use of vertically integrated sectors, which allow us to better quantify and disaggregate the pollution that is produced in all the sectors. As we will see, this approach is closer to the analyses that use the coefficients of the inverse matrices than those which employ only the direct linkages. This approach has its origin in the proposals of Sraffa (1960) and Pasinetti (1977). Under certain formal conditions, the economy can be divided into as many sub-economies as there are goods. Such a sub-economy is what Sraffa (1960) describes as a sub-system and what Pasinetti (1977) calls a vertically integrated sector.

On the basis of the Leontief inverse, if we pre-multiply this by the vector of direct labour coefficients, we obtain what Pasinetti describes as *vertically integrated labour coefficients*, $\boldsymbol{\lambda} = \mathbf{l}\ (\mathbf{I} - \mathbf{A})^{-1}$, which, for each sector, represent the amount of direct and indirect labour embodied into the productive process per unit of final demand. If we now use other vectors of direct inputs, we will obtain coefficients that measure the amount of this input that is incorporated. Thus, if c_{kj} is the k type pollution directly incorporated into the production of one unit of good j, $\mathbf{c}_k = (c_{kj})$ will be the vector of k-pollution coefficients and $\boldsymbol{\omega}_k = \mathbf{c}_k\ (\mathbf{I\text{-}A})^{-1}$ will be the vector of k-pollution values and also the vector of vertically integrated k-pollution coefficients. If we multiply vector $\boldsymbol{\omega}_k$ by the final demands $\mathbf{y}$, we obtain $\boldsymbol{\omega}_k\,\mathbf{y} = \mathbf{c}_k\ (\mathbf{I\text{-}A})^{-1}\ \mathbf{y}$, which gives us the total amount of k-pollution. Similarly, $v_{ki} = \sum_{j=1}^{n} c_{kj}\ \alpha_{ji}\ y_i$ is the k-pollution that is generated in order to obtain the demand y_i of sector i.

On the basis of the above, we can attempt to decompose this total pollution into its significant components. Thus, if $\mathbf{x}^i$ are the column vectors of $(\mathbf{I\text{-}A})^{-1}\ \hat{\mathbf{y}}$, that is to say, the amount of outputs of all the sectors that are necessary in order to obtain the final demand of sector *i*, then we can immediately obtain the relations:

$$\mathbf{x}^{i} = \mathbf{A}\,\mathbf{x}^{i} + \mathbf{e}_{i}\, y_{i} = \mathbf{A}\,(\mathbf{I}-\mathbf{A})^{-1}\,\mathbf{e}_{i}\, y_{i} + \mathbf{e}_{i}\, y_{i} = \mathbf{H}\,\mathbf{e}_{i}\, y_{i} + \mathbf{e}_{i}\, y_{i}\ , \qquad (1)$$

where $\mathbf{e}_{i} = (0,..,0,1$; ;(*i*)$,0,..,0)'$ and $\mathbf{H} = \mathbf{A}\,(\mathbf{I}-\mathbf{A})^{-1} = (h_{ij}) = \{\Sigma$; ^{n};$_{r=1}\ a_{ir}\ \alpha_{rj}\ \}$ is the Pasinetti matrix of vertically integrated technical coefficients.

Pre-multiplying expression (1) by vector $\mathbf{c}_{k}$;^; , we obtain:

$\mathbf{c}_{k}$;^; $\mathbf{x}^{i} = \mathbf{c}_{k}$;^; $\mathbf{H}\,\mathbf{e}_{i}\, y_{i} + \mathbf{c}_{k}$;^; $\mathbf{e}_{i}\, y_{i}$ (2)

which, in expanded form, can be written as:

$(\ c_{k1}\ \alpha_{1i}\ y_{i}$;...;$c_{ki}\ \alpha_{ii}\ y_{i}$;...;$c_{kn}\ \alpha_{ni}\ y_{i}\ ) =$

Error! Error! + **Error!** (3)

The generic element on the left-hand side, $c_{kj}\ \alpha_{ji}\ y_{i}$, is the total amount of *k*-pollution incorporated directly into the productive process of sector *j* and that is necessary, directly or indirectly, in order to obtain y_{i}. We can divide this pollution into its components $c_{kj}\ h_{ji}\ y_{i}$ and $c_{ki}\ y_{i}$. The term $c_{kj}\ h_{ji}\ y_{i}$ measures the *k*-pollution generated when producing the inputs of sector *j* that are used, directly or indirectly, and destroyed in the production of the final demand y_{i} of sector i. For its part, $c_{ki}\ y_{i}$ is the *k*-pollution directly generated in the productive process of sector *i* when producing its final demand y_{i}.

The total *k*-pollution associated with the production of the final demand of sector *i*, either generated by itself or received from other sectors, is given by $v_{ki} = \Sigma$; ^{n};$_{j=1}\ c_{kj}\ \alpha_{ji}\ y_{i}$ and, from (3) we can obtain:

$$v_{ki} = \Sigma;\ ^{n};_{\substack{j=1\\ j\neq i}}\ c_{kj}\ \alpha_{ji}\ y_{i} + c_{ki}\ \alpha_{ii}\ y_{i} = \Sigma;\ ^{n};_{\substack{j=1\\ j\neq i}}\ c_{kj}\ \alpha_{ji}\ y_{i} + c_{ki}\ h_{ii}\ y_{i} + c_{ki}\ y_{i} =$$

$$\Sigma;\ ^{n};_{\substack{j=1\\ j\neq i}}\ c_{kj}\ \alpha_{ji}\ y_{i} + c_{ki}\ (\Sigma;\ ^{n};_{\substack{j=1\\ j\neq i}}\ a_{ij}\ \alpha_{ji})\ y_{i} + c_{ki}\ a_{ii}\ \alpha_{ii}\ y_{i} + c_{ki}\ y_{i}, \qquad (4)$$

which divides the k-pollution associated with the demand y_i into four components. The first, $\delta_{ki} = \sum_{j=1, j \neq i}^{n} c_{kj} \, \alpha_{ji} \, y_i$, is the k-pollution produced in other sectors to generate inputs that are purchased, used and destroyed by sector i (it is the true polluting backward linkage that sector i produces in the other sectors of the economy). The second, $s_{ki} = c_{ki} \left(\sum_{j=1, j \neq i}^{n} a_{ij} \, \alpha_{ji} \right) y_i$, measures the k-pollution generated in sector i to obtain the inputs that it sells to other sectors and that these require to obtain the inputs that sector i purchases from them in order to produce its final demand. As a consequence, it represents that part of the k-pollution generated by sector i that is sold but which subsequently returns to it. The third, $r_{ki} = c_{ki} \, a_{ii} \, \alpha_{ii} \, y_i$, is the k-pollution generated by sector i to produce inputs which it uses itself to obtain its final demand. Finally, $f_{ki} = c_{ki} \, y_i$, is the pollution directly generated in the production of the final demand. The sum of the first three components is the pollution necessary in order to have the inputs available and, in this sense, we could describe it as *inputs* pollution. By contrast, the fourth could be described as *final demand* pollution.

Note that the first component is *outside* pollution, or that not coming from the sector itself. The second is *semi-own* pollution, in that, although it is generated by the sector

and finally returns to it, it is nevertheless associated to the production of other sectors during some stage of the productive process. The third has a totally *own* pollution character, in that it is generated by sector i and accumulates in the inputs of the sector itself. Finally, the fourth also has an *own* pollution character. As can be seen, the four components perfectly locate the origin and destination of the pollution generated in sector i, allowing for greater precision in the quantification of the polluting backward linkage and of the backward linkage components of each sector.

Finally, we can complete this view of the backward linkages with an analysis of the forward linkages, that is to say, of the pollution generated by sector *i* and sold to the other sectors of the economy without it finally returning to that sector. The *k*-pollution incorporated through the production of sector *i* is $c_{ki}\ x_i$. One part is produced when obtaining the final demand, $c_{ki}\ y_i$; another is generated in obtaining inputs, which are consumed in the sector itself, $c_{ki}a_{ii}\alpha_{ii}y_i$; and a third is incorporated in the sales that sector *i* makes to the other sectors of the economy, but which returns to it through the inputs that it purchases, $c_{ki}\ (\sum_{j=1, j\neq i}^{n} a_{ij}\ \alpha_{ji})y_i$. Therefore, the rest:

$$\Delta_{ki} = c_{ki}\ x_i - c_{ki}\ y_i - c_{ki}\ a_{ii}\ \alpha_{ii}\ y_i - c_{ki}\ (\sum_{j=1, j\neq i}^{n} a_{ij}\ \alpha_{ji})y_i = c_{ki}\ x_i - c_{ki}\ (1 + h_{ii})y_i = c_{ki}\ x_i - c_{ki}\ \alpha_{ii}\ y_i,$$

will be the pollution produced by sector *i* that is *sold and not returned*.

As a result, Δ_{ki} allows us to characterise the true polluting forward linkage of sector *i* in the economy, given that it is a forward linkage that does not compute the sales to itself or the sales that will later be returned to it. This difference,

$$d_i = v_{ki} - c_{ki}\ x_i = \sum_{j=1, j\neq i}^{n} c_{kj}\ \alpha_{ji}\ y_i - \Delta_{ki},$$

tells us whether the true polluting backward linkage (the purchases of pollution from others) or the true polluting forward linkage (the non-returnable sales of production to others) is the larger. If d_i is positive, then sector *i* is an overall polluting puller and others sectors pollute for it. By contrast, if d_i is negative, then *i* is an overall polluting pusher and pollutes in order for other sectors to obtain their final demands.

In summary, we can say that for a specific demand of the economy, the polluting backward and forward linkages of one sector can be totally described by the five components obtained from the pollution values, that is to say: δ_{ki}, s_{ki}, r_{ki}, f_{ki} and Δ_{ki}.

4. Vertically integrated indexes

The different components of the k-pollution of sector i provide us with information on the numerical values of this pollution. However, they tell us little with respect to the relative values. To remedy this, we can follow Rasmussen and use the components to construct the following five relative indices: $I^{1;ki}$, $I^{2;ki}$, $I^{3;ki}$, $I^{4;ki}$ and $I^{5;ki}$:

$I^{1;ki}$ = **Error!**, with δ_{ki} = **Error!**$c_{kj}\ \alpha_{ji}\ y_i$;

$I^{2;ki}$ = **Error!**, with $\Delta_{ki} = c_{ki}\ x_i - c_{ki}\ \alpha_{ii}\ y_i$;

$I^{3;ki}$ = **Error!**, with $s_{ki} = c_{ki}$ (**Error!** $a_{ij}\ \alpha_{ji}$) y_i ;

$I^{4;ki}$ = **Error!**, with $r_{ki} = c_{ki}\ a_{ii}\ \alpha_{ii}\ y_i$;

and $I^{5;ki}$ = **Error!**, with $z_{ki} = s_{ki} + r_{ki} = c_{ki}$ (**Error!** $a_{ij}\ \alpha_{ji}$)y_i ;

which we call respectively *vertically integrated polluting backward linkage index, vertically integrated polluting forward linkage index*, *vertically integrated self-pollution by outside inputs index, vertically integrated self-pollution by own inputs index* and *vertically integrated self-pollution by inputs index*.

Note that both $I^{1;ki}$ and $I^{2;ki}$ are net. A high $I^{1;ki}$ will be found in those sectors which force other sectors to pollute for them. High values for $I^{2;ki}$ will correspond to sectors which are strong polluters in order to generate the inputs of other sectors. $I^{3;ki}$, $I^{4;ki}$ and $I^{5;ki}$ measure the different components of the self-pollution.

Finally, the following two indexes, namely $I^{6;ki}$ and $I^{7;ki}$.

$I^{6;ki}$ = **Error!** , with $\varepsilon_{ki} = \delta_{ki} + s_{ki} + r_{ki}$,

and $I^{7;ki}$ = **Error!** , where $f_{ki} = c_{ki}\ y_i$,

allow us to compare the sectors in relation to their pollution by inputs and by demand.

Attention should be drawn to the fact that these seven indexes depend on the final demands y_i, given that these are used to define δ_{ki} , Δ_{ki} , s_{ki} , r_{ki} and f_{ki}. In this way, we can overcome the character of the simple sector ratios (not weighted either by demand or by production) of the Rasmussen indexes. Undoubtedly, we could obtain technical definitions technical, independent of the specific final demands, by using the final demands of the balanced growth.

These proposed indexes are similar to, although more informative than, those of Rasmussen. Indeed, when the final demands of all the sectors are equal (for convenience, we can assume that they are 1), it is easy to determine the following relations:

$I^{1;ki}$ = **Error!** = **Error!** = **Error!** ;

$I^{2;ki}$ = **Error!**= **Error!** = **Error!** = **Error!**; [1]

Error! = **Error!** = **Error!** = **Error!** ;

Error! = **Error!** = **Error!** = **Error!** ;

Thus, in our view, the indexes $I^{1;ki}$, $I^{2;ki}$, $I^{3;ki}$, $I^{4;ki}$, $I^{5;ki}$, $I^{6;ki}$ and $I^{7;ki}$ represent a significant improvement to the traditional Rasmussen-type coefficients based on inverse matrices, because:

- they include these as particular cases,
- they are not simple ratios and weigh each type of pollution by the final demand of each sector,
- they throw light on the problem of self-consumption,
- they clearly show the origins and final uses of the pollution.

For these reasons, the $I^{j;ki}$ allow us to obtain more explanatory classifications of the sectors. Table 3 illustrates one of these based on $I^{1;ki}$, $I^{2;ki}$, $I^{5;ki}$ e $I^{7;ki}$. The values of the indexes vary from 0 to 1. We can say that they have high values when they are close to 1 and low values when they are close to 0.

(Table 3 about here)

5. Application to the Aragonese economy

As an example of the possibilities of vertical integration analysis for characterising sectors in relation to water pollution, we propose to study the Aragonese economy. Aragón is a region lying in the Ebro Valley in North-eastern Spain and which is characterised by its significant water pollution problems. We will be working with regional coefficients obtained from IBERCAJA (1995) and the demand will be given by the net domestic demand (see Pulido and Fontela, 1993). The economy has been aggregated into 21 sectors that are representative from the economic and environmental points of view. These sectors are *Cereal crops under irrigation (1), industrial crops (2), Vegetables (3), Fruits (4), Other crops under irrigation (5), Dry land crops (6), Livestock (7), Energy (8), Metals (9), Non-metals (10), Chemicals (11), Motor vehicles (12), Dairy products and juices(13), Wine production (14), Other foods (15), Manufacturing (16), Paper (17), Construction (18), Hotels and catering (19), Health services (20)* and *Other services (21).* The vectors of direct pollution coefficients has been previously calculated for Water returns, BDO5, SS, Nitrates and Phosphates on the basis of the WHO (1984), the Junta de Andalucia (1996), Tabuenca (1995) and CHE (1992).

In Table 4 we present the value of four of the earlier-defined components and the total value in pollution of each type, whilst Table 5 contains the values of the indexes associated to these four components.

(Tables 4 and 5 about here)

If, in Table 4, we concentrate on the Water returns, we can see that the agriculture under irrigation sectors (sectors 1 to 5) are responsible for the majority of the pollution and that they essentially stand-out by virtue of the high level of own pollution. When comparing the components Δ_{ki} and δ_{ki}, it is clear that all the agricultural sectors are polluting pushers in relation to Water returns. Furthermore, agriculture under irrigation is responsible for more than 75% of the sales of Water return pollution to other sectors of the economy, with the contribution of Cereal crops under irrigation (sector 1) being particularly relevant, with 52.1%. The irrigation sectors similarly stand-out because of the high pollution associated directly to the final demand, with the component f_{ki} being the highest in all cases.

On the other hand, the Livestock sector purchases twice the amount that it sells in terms of water return pollution. The weight of this pollution generated directly by this sector is relatively high if we compare it with its Water returns value, with the former being some 66% of the latter, and with 62.9% of this percentage corresponding to final demand.

The food industry (sectors 13, 14 and 15) is an extreme case of a Water returns-purchasing sector. Indeed, the three food sectors buy more than 63% of Water returns generated by the other sectors of the economy. Other purchasing sectors of this type of pollution are the Motor vehicles, Construction, Hotels and catering and Health services sectors.

Turning to BDO5 pollution, the most relevant aspect is the strong association with sector 9, Metals, whose final demand has a BDO5 value of 2,014,540 tons, representing 65.8% of the BDO5 value of the economy.

The forward linkage sectors are Livestock and Metals, whose sales of pollution to other sectors of 132,170 and 328,580 tons, respectively, jointly represent the 88.8% of the

BDO5 sales in the economy. The Manufacturing and Paper sectors are also forward linkage, although to a lesser extent.

The largest purchaser of this pollution is the Motor vehicles sector with 117,610 ton. To a lesser extent, the Construction (77,610 tons), Hotels and catering (15,160 tons), Other services (53,390 tons) and Livestock (13,820 tons) sectors are also purchasers of BDO5 pollution.

As regards SS pollution, we can note that Livestock and Other foods are the sectors that concentrate this type of pollution, with their SS values being some 60.3% of the SS value of the economy as a whole. Livestock is also the main seller, with 242,410 tons, representing 68.1% of the total sales of the system. However, it directly generates the majority of its pollution in order to obtain its final demand. The main purchaser from Livestock is the Other foods sector, which receives 191,620 tons, representing some 95.97% of its total value in SS.

With respect to both Nitrates and Phosphates, the only sectors that generate pollution (without receiving it from others) are those of agriculture under irrigation, Hotels and catering and, fundamentally, Livestock. This last sector has a Nitrates value of 73,350 tons and a Phosphates value of 44,540 tons, which suppose 59.1% and 66%, respectively, of the total pollution of these two types in the economy. The Livestock sector is the largest forward linkage sector in these two types of pollution and the sectors that are most dependent on it (essentially the food industries) will have the largest backward linkages.

In summary, from a study of the Aragonese economy based on Table 4, we can identify sectors that are clearly orientated towards one particular type of pollution. Thus, Agriculture is orientated towards Water returns; Metals towards BDO5; and Livestock towards SS, Nitrates and Phosphates, with all of these sectors being relevant for their self-pollution and forward linkage.

By way of Table 5, we can also characterise some sectors of the Aragonese economy under the criteria set out in Table 3. The results, which are presented in Table 6, confirm what we have said earlier. Here, we should first recall that in Table 3 the sectors are differentiated by the high or low value of the indexes, which supposes that not all of the sectors are included[2]. We consider the largest seven values of the index to be high and the smallest seven to be low. All the zero values will be low, although there might be more than seven, whilst all those that are equal to an intermediate value will also be considered as low. This means that the sectors appearing in Table 6 are relevant in the earlier mentioned aspects and do not represent average situations.

(Table 6 about here)

6. Conclusions

In this paper we have totally disaggregated the pollution associated to the demand of a sector into five representative components, using Pasinetti's approach of vertically integrated sectors. On the basis of these components, we have proposed a number of indexes that try to overcome some of the deficiencies of the traditional Rasmussen-type indexes. As a result, we have been able to carry out a more complete analysis, in the sense of identifying the key sectors, that is to say, those exhibiting forward or backward linkages in pollution. In a second stage, we have applied this methodology to the study of five pollution parameters (Water returns, BDO5, SS, Nitrates and Phosphates) in the economy of the Aragon region of Spain.

The following elements have emerged as the most relevant. First, the vertical integration methodology represents an advance when seeking to describe the intersectoral linkages, in the sense that it allows for the total decomposition of the sales and purchases of pollution that are carried out by a sector. Associated to this decomposition, the relative indexes we have obtained improve the measurement of these linkages. They detail the polluting character of each sector and avoid the simple ratios problem of other Rasmussen-type indexes, with these becoming a particular case of those presented in this paper.

Furthermore, the polluting properties of the productive structure we analyse are not the same for all the pollutants. That is to say, we cannot propose an improvement in the quality of water in a generic manner; rather, it is necessary to delimit the parameters that we wish to improve. For example, if we want to control the volume of BDO5 or of SS, rather than the total mass of Nitrates and Phosphates, then more attention would have to be paid to the industrial sectors.

In any event, we find that irrigation-based agriculture and livestock appear to be the relevant sectors with respect to Water returns (agriculture) and to the other pollution parameters we have analysed (livestock). The strong polluting character of the Livestock sector has its fundamental origin in the orientation of the Aragonese economy towards pig production. Thus, any measure aimed at improving the quality of water in this region must give serious consideration to the problems associated with this activity.

Furthermore, the results also demonstrate that both Agriculture and Livestock generate a large part of the Water returns and of the pollution in the economy when obtaining the outputs that other sectors demand for their production. Thus, whilst the food industry is the main engine for the growth and maintenance of agro-livestock activity, it is also the main destination of the pollution of these sectors (as far as intermediate demand is concerned). In this regard, steps which are taken in one of these two areas will have repercussions on the economic and environmental behaviour of the other.

Finally, it should be noted that despite the importance of the agriculture sectors in terms of pollution, not all of this can be attributed to them. Whilst an improvement in the pollution levels of these sectors would help to reduce the pressure on the water resource, it would not eliminate it. Here, we should not forget that other sectors, such as Metals, Energy, Paper or Manufacturing also present significant indexes. The high spatial concentration that characterises industrial activities supposes severe damage for the water environment in which these activities are located.

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Footnotes:

[1] It should be remembered that $(\mathbf{I}\text{-}\mathbf{A})^{-1} - \mathbf{I} - \mathbf{A}\,(\mathbf{I}\text{-}\mathbf{A})^{-1} = \mathbf{0}$

[2]If we want all of the sectors to the included in the typology of Table 3, then one possible criterion is to fix an appropriate value of the index with respect to which we can speak of high or low values, for example, the average value of the index.

TABLES

Table 1

	High w_i	**Low w_i**
High u_j	Intermediate manufactures	Final manufactures
Low u_j	Primary production of intermediate goods	Final primary production

Table 2

	U_j >1	**U_j <1**
W_i >1	Key sectors (high relatively backward and forward linkages)	Forward linkage sectors (only the forward linkage is relevant)
W_i <1	Backward linkage sectors (only the backward linkage is relevant)	Non-significant sectors

Table 3

Sectoral characterisation according to their polluting character

Sector indexes				**Relevant characteristics**
$I^{1;ki}$	$I^{2;ki}$	$I^{5;ki}$	$I^{7;ki}$	
High	High	High	High	Key sector. Self-polluter by inputs and demand
			Low	Key sector. Self-polluter by inputs
		Low	High	Key sector. Self-polluter by demand
			Low	Key sector. Non self- polluter
	Low and $d_i > 0$	High	High	Backward linkage sector. Self-polluter by inputs and demand
			Low	Backward linkage sector. Self-polluter by inputs
		Low	High	Backward linkage sector. Self-polluter by demand
			Low	Backward linkage sector. Non self-polluter
Low	High and $d_i < 0$	High	High	Forward linkage sector. Self-polluter by inputs and demand
			Low	Forward linkage sector. Self-polluter by inputs
		Low	High	Forward linkage sector. Self-polluter by demand
			Low	Forward linkage sector. Non self-polluter
	Low	High	High	Self-polluter by inputs and demand
			Low	Self-polluter by inputs
		Low	High	Self-polluter by demand
			Low	Non polluter

Table 4

Sharing of total contamination in five components (water returns in hm^3 and the rest in thousands of tons)																							
Sectors*		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**Total**
Water Return	δ_{ki}	0.61	0.33	0.26	0.52	0.09	0.32	29.32	0.41	2.79	0.29	1.05	3.32	17.29	9.95	110.47	3.74	2.14	7.46	16.58	1.05	7.21	215.20
	Δ_{ki}	112.16	19.94	12.15	18.93	9.00	0.00	11.49	0.73	2.13	6.01	3.62	0.02	0.14	2.11	1.19	3.13	5.78	0.47	1.18	0.02	5.00	215.20
	z_{ki}	6.57	1.14	0.70	1.10	0.51	0.00	1.34	0.22	1.08	0.45	1.61	0.01	0.01	0.12	0.69	1.05	0.63	0.02	0.02	0.08	4.30	21.65
	f_{ki}	177.36	31.50	19.19	29.91	14.21	0.00	21.75	0.47	11.93	3.57	31.88	3.25	4.72	4.77	5.52	15.04	14.53	2.92	14.95	2.30	18.07	427.87
	v_{ki}	184.54	32.97	20.15	31.52	14.81	0.32	52.41	1.10	15.81	4.31	34.54	6.59	22.02	14.84	116.69	19.83	17.31	10.40	31.56	3.43	29.57	664.71
BDO5	δ_{ki}	12.58	5.23	4.16	8.27	1.34	4.91	13.82	9.58	7.74	7.43	5.68	117.61	16.68	2.89	121.88	21.69	6.24	77.61	15.16	5.10	53.39	519.00
	Δ_{ki}	0.00	0.00	0.00	0.00	0.00	0.00	132.17	0.00	328.58	7.12	4.55	0.01	0.17	0.44	1.78	33.66	9.65	0.52	0.35	0.00	0.00	519.00
	z_{ki}	0.00	0.00	0.00	0.00	0.00	0.00	15.38	0.00	166.60	0.54	2.02	0.00	0.02	0.03	1.03	11.27	1.06	0.02	0.01	0.00	0.00	197.97
	f_{ki}	0.00	0.00	0.00	0.00	0.00	0.00	250.21	0.00	1840.19	4.23	40.05	1.06	5.91	1.00	8.21	161.86	24.26	3.22	4.42	0.00	0.00	2344.63
	v_{ki}	12.58	5.23	4.16	8.27	1.34	4.91	279.41	9.59	2014.54	12.19	47.76	118.68	22.60	3.92	131.12	194.82	31.56	80.85	19.58	5.10	53.39	3061.60
SS	δ_{ki}	5.97	2.48	1.97	3.92	0.64	2.33	4.20	0.50	12.21	1.31	5.73	12.32	22.95	2.05	191.62	13.18	3.13	14.15	27.84	2.79	24.72	356.02
	Δ_{ki}	0.00	0.00	0.00	0.00	0.00	0.00	242.41	54.65	3.14	7.08	4.32	0.00	0.06	11.37	1.55	24.30	6.37	0.25	0.52	0.00	0.00	356.02
	z_{ki}	0.00	0.00	0.00	0.00	0.00	0.00	28.20	16.58	1.59	0.53	1.92	0.00	0.01	0.64	0.90	8.14	0.70	0.01	0.01	0.00	0.00	59.24
	f_{ki}	0.00	0.00	0.00	0.00	0.00	0.00	458.90	35.15	17.57	4.21	38.11	0.45	2.03	25.73	7.15	116.86	16.01	1.53	6.63	0.00	0.00	730.33
	v_{ki}	5.97	2.48	1.97	3.92	0.64	2.33	491.30	52.24	31.37	6.05	45.76	12.78	24.99	28.42	199.67	138.18	19.83	15.69	34.48	2.79	24.72	1145.58
Nitrates	δ_{ki}	0.67	0.28	0.22	0.44	0.07	0.26	0.88	0.01	0.07	0.01	0.04	0.07	3.76	0.46	30.65	0.93	0.13	0.06	2.16	0.10	0.31	41.59
	Δ_{ki}	3.75	0.42	0.25	0.37	0.30	0.33	36.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.00	0.00	41.59
	z_{ki}	0.22	0.02	0.01	0.02	0.02	0.02	4.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.51
	f_{ki}	5.93	0.66	0.39	0.58	0.47	0.52	68.28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.00	0.00	78.11
	v_{ki}	6.82	0.97	0.63	1.05	0.56	0.81	73.35	0.01	0.07	0.01	0.04	0.07	3.76	0.46	30.65	0.93	0.13	0.06	3.44	0.10	0.31	124.21
Phosphates	δ_{ki}	0.41	0.17	0.14	0.27	0.04	0.16	0.01	0.00	0.03	0.00	0.02	0.04	2.00	0.10	16.92	0.55	0.04	0.03	1.09	0.05	0.14	22.21
	Δ_{ki}	0.02	0.00	0.00	0.00	0.00	0.00	22.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	22.21
	z_{ki}	0.00	0.00	0.00	0.00	0.00	0.00	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.58
	f_{ki}	0.04	0.00	0.00	0.00	0.00	0.00	41.95	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.25	0.00	0.00	42.25
	v_{ki}	0.45	0.17	0.14	0.27	0.05	0.16	44.54	0.00	0.03	0.00	0.02	0.04	2.00	0.10	16.92	0.55	0.04	0.03	1.34	0.05	0.14	67.05

* Used sectors: 1: *Cereal crops under irrigation*, 2: *Industrial crops*, 3: *Vegetables*, 4: *Fruits*, 5: *Other crops under irrigation*, 6: *Dry land crops*, 7: *Livestock*, 8: *Energy*, 9: *Metals*, 10: *Non metals*, 11: *Chemicals*, 12: *Motor vehicles*, 13: *Dairy products and juices*, 14: *Wine production*, 15: *Other foods*, 16: *Manufacturing*, 17: *Paper*, 18: *Construction*, 19: *Hotels and catering*, 20: *Health services*, 21: *Other services*.
Source: Own calcutations

Table 5

Index sectoral values for the five types of water contamination																							
Sectors*		*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*total*
Water Return	I^1	0.003	0.002	0.001	0.002	0.000	0.001	0.136	0.002	0.013	0.001	0.005	0.015	0.080	0.046	0.513	0.017	0.010	0.035	0.077	0.005	0.033	1.000
	I^2	0.521	0.093	0.056	0.088	0.042	0.000	0.053	0.003	0.010	0.028	0.017	0.000	0.001	0.010	0.006	0.015	0.027	0.002	0.005	0.000	0.023	1.000
	I^5	0.303	0.053	0.032	0.051	0.024	0.000	0.062	0.010	0.050	0.021	0.074	0.001	0.001	0.006	0.032	0.048	0.029	0.001	0.001	0.004	0.198	1.000
	I^7	0.415	0.074	0.045	0.070	0.033	0.000	0.051	0.001	0.028	0.008	0.075	0.008	0.011	0.011	0.013	0.035	0.034	0.007	0.035	0.005	0.042	1.000
BDO5	I^1	0.024	0.010	0.008	0.016	0.003	0.009	0.027	0.018	0.015	0.014	0.011	0.227	0.032	0.006	0.235	0.042	0.012	0.150	0.029	0.010	0.103	1.000
	I^2	0.000	0.000	0.000	0.000	0.000	0.000	0.255	0.000	0.633	0.014	0.009	0.000	0.000	0.001	0.003	0.065	0.019	0.001	0.001	0.000	0.000	1.000
	I^5	0.000	0.000	0.000	0.000	0.000	0.000	0.078	0.000	0.842	0.003	0.010	0.000	0.000	0.000	0.005	0.057	0.005	0.000	0.000	0.000	0.000	1.000
	I^7	0.000	0.000	0.000	0.000	0.000	0.000	0.107	0.000	0.785	0.002	0.017	0.000	0.003	0.000	0.004	0.069	0.010	0.001	0.002	0.000	0.000	1.000
SS	I^1	0.017	0.007	0.006	0.011	0.002	0.007	0.012	0.001	0.034	0.004	0.016	0.035	0.064	0.006	0.538	0.037	0.009	0.040	0.078	0.008	0.069	1.000
	I^2	0.000	0.000	0.000	0.000	0.000	0.000	0.681	0.154	0.009	0.020	0.012	0.000	0.000	0.032	0.004	0.068	0.018	0.001	0.001	0.000	0.000	1.000
	I^5	0.000	0.000	0.000	0.000	0.000	0.000	0.476	0.280	0.027	0.009	0.032	0.000	0.000	0.011	0.015	0.137	0.012	0.000	0.000	0.000	0.000	1.000
	I^7	0.000	0.000	0.000	0.000	0.000	0.000	0.628	0.048	0.024	0.006	0.052	0.001	0.003	0.035	0.010	0.160	0.022	0.002	0.009	0.000	0.000	1.000
Nitrates	I^1	0.016	0.007	0.005	0.011	0.002	0.006	0.021	0.000	0.002	0.000	0.001	0.002	0.090	0.011	0.737	0.022	0.003	0.001	0.052	0.002	0.007	1.000
	I^2	0.090	0.010	0.006	0.009	0.007	0.008	0.867	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	1.000
	I^5	0.049	0.005	0.003	0.005	0.004	0.004	0.930	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
	I^7	0.076	0.009	0.005	0.007	0.006	0.007	0.874	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.016	0.000	0.000	1.000
Phosphates	I^1	0.018	0.008	0.006	0.012	0.002	0.007	0.000	0.000	0.002	0.000	0.001	0.002	0.090	0.005	0.761	0.025	0.002	0.001	0.049	0.002	0.006	1.000
	I^2	0.001	0.000	0.000	0.000	0.000	0.000	0.998	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	1.000
	I^5	0.001	0.000	0.000	0.000	0.000	0.000	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.000
	I^7	0.001	0.000	0.000	0.000	0.000	0.000	0.993	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	1.000

* Used sectors: 1: *Cereal crops under irrigation*, 2: *Industrial crops*, 3: *Vegetables*, 4: *Fruits*, 5: *Other crops under irrigation*, 6: *Dry land crops*, 7: *Livestock*, 8: *Energy*, 9: *Metals*, 10: *Non metals*, 11: *Chemicals*, 12: *Motor vehicles*, 13: *Dairy products and juices*, 14: *Wine production*, 15: *Other foods*, 16: *Manufacturing*, 17: *Paper*, 18: *Construction*, 19: *Hotels and catering*, 20: *Health services*, 21: *Other services*.
Source: Own calculations

Tabla 6: Sectoral characterisation of Aragonese economy according to their polluting character

Sector indexes				Relevant characteristics	Pollution type				
$I^{1;ki}$	$I^{2;ki}$	$I^{5;ki}$	$I^{7;ki}$		***Water returns***	***BDO5***	***SS***	***Nitrates***	***Phosphates***
High	High	High	High	Key sector. Self-polluter by inputs and demand	Livestock	Other foods. Manufacturing	Manufacturing	Cereal crops under irrigation Livestock	Cereal crops under irrigation
			Low	Key sector. Self-polluter by inputs					
		Low	High	Key sector. Self-polluter by demand					Hotels and catering
			Low	Key sector. Non self- polluter					
	Low and $d_i > 0$	High	High	Backward linkage sector. Self-polluter by inputs and demand	Other services				
			Low	Backward linkage sector. Self-polluter by inputs					
		Low	High	Backward linkage sector. Self-polluter by demand		Dairy products and juices		Hotels and catering	
			Low	Backward linkage sector. Non self-polluter	Construction	Motor vehicles Other services	Other services	Dairy products and juices Other foods Manufacturing	Industrial crops; Fruits Dairy products and juices Other foods Manufacturing
Low	High and $d_i < 0$	High	High	Forward linkage sector. Self-polluter by inputs and demand	Cereal crops under irrigation Industrial crops Fruits	Livestock Metals Paper	Livestock Energy Paper	Industrial crops Dry land crops	Livestock
			Low	Forward linkage sector. Self-polluter by inputs					
		Low	High	Forward linkage sector. Self-polluter by demand					
			Low	Forward linkage sector. Non self-polluter					
	Low	High	High	Self-polluter by inputs and demand					
			Low	Self-polluter by inputs					
		Low	High	Self-polluter by demand					
			Low	Non polluter	Dry land crops	Industrial crops Vegetables Other crops under irrigation Dry land crops Health services	Industrial crops Vegetables Other crops under irrigation Dry land crops	Energy Non metals Chemicals Construction	Energy Chemicals Non metals Construction