Methodological note about the determination of "Key" sectors in final energy consumption: a preliminary approach to the Spanish case

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Abstract

In this paper we analyze the determination of "key" sectors in the final energy consumption. We approach this issue from an input-output perspective and we design a methodology based on the elasticities of the demands of final energy consumption. As an exercise, we apply the proposed methodology to the Spanish economy. The analysis allows us to indicate the greater or lesser relevance of the different sectors in the consumption of final energy, pointing out which sectors deserve greater attention in the Spanish case and showing the implications for energy policy.

Keywords: Energy consumption elasticities, Input-output, "Key" sectors

Introduction

By the end of 1997, the Kyoto Protocol committed industrialized countries (Annex B of the Protocol) to limiting their greenhouse gases emissions. With a view to complying with this commitment, the European Union (EU) established a distribution of burdens for its members that implied a total cutback of 8% in relation to 1990 levels for the following six gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). In the case of Spain, the agreement of the Presidency of the Environmental Council in June 1998 allowed a 15% increase in emissions in relation to 1990 levels by 2008-2012. Although the purpose of this paper is to determine the "key" productive sectors in the final energy consumption in Spain, given the close relationship between energy consumption and the greenhouse gases emissions the results are of great interest in the design of environmental policies designed to achieve the aforementioned objective.

The cutback in emissions and the maintenance of social well-being require a fragile balance between policies that often have opposite effects. Hence, it is very important to determine the link between economic performance and energy consumption. Emissions of greenhouse gases are closely linked to the energy consumption of primary energy, especially CO_2 emissions, but the final sectoral consumption is crucial for the consumption of primary energy. In fact, energy demand is a derived demand that depends on the productive structure of the economy, the energy content,[1] the sectoral production, the age of the stock of capital (as long as energy transformers), etc... as Galletto (1999) has wisely shown for the Spanish economy. Therefore, although we support the need to approach energy analysis in terms of primary energy (Alcántara and Roca, 1995), it is also interesting to show the sectoral economic performance in relation to the consumption of final energy. To a great extent, the consumption of energy responds to the sectoral energy content and, given certain demand and supply sectoral structures of the economy, the response of the demand of final energy to a general increase in economic activity depends both on the energy content of the different sectors and on the technological structure of the economy. Therefore, the role played by the different productive sectors in the consumption of final energy should be determined according to these structural determinants.

In this paper we develop a methodology that allows us to determine the "key" sectors in the consumption of final energy and we apply it to the Spanish economy. Although it is very important to link the consumption of final and primary energy, our analysis is also quite significant and allows us to show the relative incidence of the different productive sectors according to the factors quoted in the previous paragraph.

Methodology

The concept of "key" sectors, developed by Rasmusen (1956), in which these sectors are determined by the multiplier effects of final demand, has enjoyed great

[1] We use the term "energy content" to denote the final energy directly and indirectly necessary in the production of one unit of final output. By "final energy intensity" we denote the relationship between direct final energy consumption in, for example, tons of equivalent petroleum (TEP), and total or sectoral gross production in monetary units at constant prices. To denote the same relationship, but in terms of primary energy, we talk about "energy intensity".

prestige in the literature, in spite of its limitations. The author himself shows a number of these limitations, but there are some more disqualifying criticisms, such as those by Skolka (1986).[2] We will not discuss all these questions here, although the methodology suggested in this paper could be considered as an alternative proposal to those which, from different perspectives, have derived from Rasmusen's original concept. Of course, we also take that original idea as our starting point. The proposed method is an adaptation to energy analysis of the method developed in Alcántara (1985) and consists of an extension of the disaggregated calculation of the production/demand elasticity proposed by Pulido and Fontela (1993; pp. 82-84).

Let E be a scalar denoting the total final energy used by the productive system, and let **e**' be a row vector of final energy per unit of sectoral output. From the well-known model of Leontief, we can write:

$$(1) \qquad E = \mathbf{e}'\mathbf{x} = \mathbf{e}'(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}$$

differentiating (1) and expressing the increase in final demand as a proportion of this demand:

$$(2) \qquad \Delta E = \mathbf{e}'\Delta\mathbf{x} = \mathbf{e}'(\mathbf{I}-\mathbf{A})^{-1}\mathbf{y}\alpha$$

where α is the proportional increase in final demand.

We now define a vector of the share of the final sectoral demands in their respective effective output:

[2] Hazari and Krishnamurty (1970) present a redefinition of the multipliers of Rasmusen, considering the sectoral weights of final demand, with the aim of determining key sectors.

(3) $$\mathbf{s} = \hat{\mathbf{x}}^{-1}\mathbf{y}$$

where ^ denotes the diagonalization of the corresponding vector. We can rewrite (2) as follows:

(4) $$\Delta E = \mathbf{e}'(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{x}}\mathbf{s}\alpha$$

dividing by E, we obtain:

(5) $$E^{-1}\Delta E = E^{-1}\mathbf{e}'(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{x}}\mathbf{s}\alpha$$

which shows the total increase in final energy in relation to the increase in final demand. That is to say, the elasticity of *E* with respect to final demand. But this expression does not tell us anything, given the lineal nature of the model, since $E^{-1}\Delta E = \alpha$. Therefore, what is of interest to us is a sectoral disaggregation of the elasticity in order to obtain relevant information. With this aim, we do some transformations to expression (5).

Let **f**' = (f_1, f_2, ..., f_i, ..., f_n) be a vector of the distribution of final energy among the *n* productive sectors, so that $\sum_i f_i = 1$. The vector of sectoral consumption coefficients of final energy **e**' can be expressed as follows:

(6) $$\mathbf{e}' = E\mathbf{f}'\hat{\mathbf{x}}^{-1}$$

and substituting this in (5):

(7) $$E^{-1}\Delta E = \mathbf{f}'\hat{\mathbf{x}}^{-1}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{x}}\mathbf{s}\alpha$$

if we now consider (Miller and Blair, 1985; p. 360):

(8) $$\hat{\mathbf{x}}^{-1}(\mathbf{I}-\mathbf{A})^{-1}\hat{\mathbf{x}} = (\mathbf{I}-\mathbf{D})^{-1}$$

where $d_{ij} = X_{ij} / X_i$ is the characteristic element of matrix **D**, which is just the matrix of horizontal, or distribution, coefficients of an input–output table. Substituting (8) in (7) and diagonalizing vector **s** we obtain:

$$(9) \qquad \varepsilon' = \mathbf{f}'(\mathbf{I}-\mathbf{D})^{-1}\hat{\mathbf{s}}\alpha$$

which gives us the proportional variation of sectoral energy consumption in relation to a proportional change in final demand. For a more accurate interpretation of this last conclusion, we diagonalize vector **f**' and omit α for the moment, so we can write:

$$(10) \qquad \mathbf{E}^{y} = \hat{\mathbf{f}}(\mathbf{I}-\mathbf{D})^{-1}\hat{\mathbf{s}}$$

E^{y}_{ij}, the characteristic element of matrix E^y, expresses the percentage of increase in the consumption of final energy of sector *i* in response to a 1% change in the final demand of sector *j*, and it can be interpreted as elasticity, in such a way that the sum of the elements of the sector *j* column expresses the percentage of variation of such energy consumption experienced by the whole economy in response to a 1% change experienced by sector *j*. Of course, the sum by rows of this matrix reproduces the sectoral distribution of energy consumption and is an indicator of the impact that would have a global economic increase of 1% in each of the sectors. The sum by columns has a correspondence with the Rasmusen's (1956) *backward linkage* while the sum by rows has a correspondence with this author's *forward linkage*. However, notice that both the structure of output distribution and the structure of demand, as well as the productive structure, according to expression (8), influence our approach as key elements of the impact of demand on energy consumption.

Application and results

If we take into account the fact that Spain experienced rates of average annual increase in final energy of the order of 3.95% during the 1990s while the EU average was 1.25% (OECD, 2001), it is worth carrying out a first analysis of the sectoral responsibilities of this behavior. The exercise is much more instructive if we compare the 35.6% increase of final energy in the decade with the 29.5% increase in CO_2 emissions experienced, in spite of the importance of nuclear energy. These results call into question the fulfillment of the aforementioned objective of not exceeding a 15% increase in the emissions of the 6 greenhouse gases by 2008-2012.

With the purpose of showing some possibilities of the approach based on "elasticities" for the determination of key sectors and conducting a first approach to the current situation, we will undertake, as an exercise, an application of the proposed methodology to the study of the consumption of final energy in Spain in 1995. The information about sectoral energy consumption has been obtained from the energy balances of the *Instituto para la diversificación y ahorro de la energía* (IDAE) (Institute for energy diversification and saving) that uses the methodology of the International Energy Agency (IEA), which allows international comparisons. The number of sectors in which the productive structure has been disaggregated is not the desirable one, but it is greater than the one of the OECD balances. The final energy consumption of the energy sector refers to its own uses as a productive sector. Therefore, it does not include the primary energy for transformation, because the study refers only to the use of final energy. One important issue, when linking energy consumption to an economic input–output table, is the allocation of the energy consumption of road transport between consumption for private use and consumption for goods transport and other types of transport by companies. We have been able to obtain this distribution from the studies carried out by the *Grupo de trabajo de Prospectiva* (1997) (Prospective workgroup). In our analysis we have not explicitly considered private car transport by road. However, the final demand of energy does include this consumption and, therefore, includes the part corresponding to the uses of the energy sector. Nevertheless, it will always involve a bias, undervaluing the impact on road transport consumption considered as a whole. Finally, the economic input–output table used is the 1995 one, estimated by Eurostat for Spain.

The computation of expression (10) gives as a result the matrix of Annex I, of which the sums by rows and columns are shown in Table I.

		Total impact	Distributive impact
1	Agriculture	0.042	0.061
2	Energy	0.043	0.098
3	Iron and steel industry and non-ferrous metallurgy	0.053	0.094
4	Non-metallic products	0.034	0.103
5	Chemicals	0.082	0.124
6	Metallic Products	0.045	0.015
7	Transport Equipment	0.054	0.012
8	Food	0.081	0.030
9	Textile and footwear	0.028	0.017
10	Paper and printing	0.015	0.020
11	Other manufactures	0.025	0.024
12	Building	0.123	0.032
13	Commerce	0.038	0.018
14	Restaurants and hotels	0.075	0.025
15	Domestic transport	0.113	0.215
16	Other transports	0.057	0.076
17	Other sales services	0.038	0.021
18	Other non-sales services	0.057	0.016

Table I. Total and sectoral impact of energy consumption

We have called *total impact* the percentage increase in final energy experienced by the whole economy in response to a 1% increase of the corresponding sector. Looking at the data in Table I, a 1% increase in final demand of the agriculture sector, for example, would lead to a 0.042% increase of total final energy consumption, while a 1% increase of the final demand of all sectors would cause a 0.061% change of the energy consumption of agriculture. We call *distributive impact* this percentage increase, which coincides with the distribution of direct sectoral consumptions. With this information about all the sectors, we can establish a preliminary sectoral taxonomy in order to show how much and in which sense a sector is relevant to energy consumption. If E_T and E_D are the median values of the total and distributive impacts, respectively, we can operate a classification such as the one established in Table II.

	$\sum_i E_{ij}^y \langle E_T$	$\sum_i E_{ij}^y \rangle E_T$
$\sum_j E_{ij}^y \rangle E_D$	A) Relevant sectors from the perspective of the demand of other sectors	B) Key sectors: push and are pushed to consume energy
$\sum_j E_{ij}^y \langle E_D$	C) Non-relevant sectors	D) Relevant sectors from the perspective of their final demand

Table II. Classification of sectors

The sectors of quadrant C would be less relevant when designing an energy saving policy, since their total impact, given by the sum of the corresponding column of matrix E^y, as well as their share in the distribution of consumption of final energy, is relatively low.

Sectors of quadrant D can be highlighted from the perspective of their final demand. They are sectors with a high energy content (direct and indirect energy consumption), although their share in the distribution of final energy is relatively low. In principle, it is likely that their final demand will be affected by energy-saving policies. However, it is worthwhile to take into account that the total impact, as we have defined it, incorporates the impact on the own sector given by the corresponding element of the principal diagonal. Hence, from the perspective of energy policy, when this own effect represents a high percentage of the total impact, then policies oriented to incentivate the energy saving of the own sector can be considered, without affecting demand. In the Spanish case, as an example in sector 14 (Restaurants and hotels), in the assumption of a 1% increase in its final demand, its total impact would be of 0.075% but the impact in the own sector would be of 0.022%, so 30% of the total impact would correspond to the own sector. Therefore, even if the total consumption of the sector is determined, basically, by final demand, it seems more appropriate to establish policies designed to save energy in the sector, rather than acting on the final demand.

In quadrant A would be placed those sectors that, in relative terms, stand out as inputs of other productive processes. Their consumption is determined, in part, by the demand of other sectors. Consequently, energy savings policies that could affect the magnitude of their production could generate bottlenecks in productive activities.

Lastly, in quadrant B would be placed those sectors that we consider to be crucial in the final energy consumption. Their total effect and their total share in energy consumption and distributive effect, have values greater than the median values of the productive sectors. Therefore, these key sectors encourage the energy consumption of other productive sectors and, at the same time, are induced by the other sectors to consume energy; hence they have such a high share in total energy consumption

Following these criteria, in Figure 1 the situation of each of the 18 sector for which it has been possible to find data is shown, following the information shown in Table I. This allows us, according to their position in relation to the median values of the total effect (0.049) and to the direct share in the energy consumption (0.274), to classify them from the point of view of Table II.

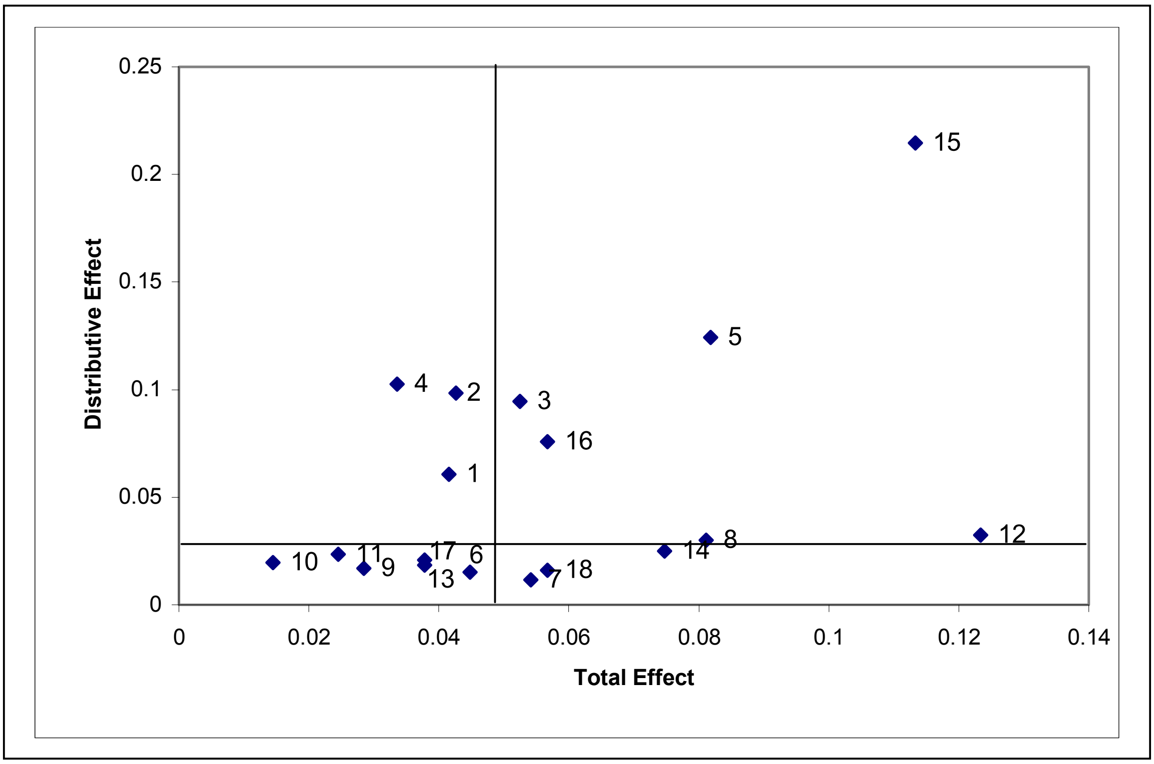

Figure 1. Classification of sectors in Spain.

In group C, as not very relevant sectors, would be placed the sectors Textile and footwear (9), Paper and printing (10), Other manufactures (11), Commerce (13), Other sales services (17) and Metal products (6). In percentage terms their impact in total consumption represents 14.4% and, as for their distributive impact, their share in the total direct consumption of final energy is 10%; these are low percentages which show their limited impact.

To group D, whose impact is determined by their final demand, belong the following sectors: Transport equipment (7), Restaurants and hotels (14) and Other non-sales services (18). While their direct consumption, that is to say, their impact on the distribution of energy consumption, represents 6.8%, their total impact is 23.1%. They are sectors whose products are mainly demanded by final consumption sectors. Before concluding that the appropriate policy to follow in the case of these sectors consists in a cutback in demand, we should consider our earlier comments about the meaning of the elements of the principal diagonal of matrix E^y. Indeed, a relatively high value of these elements means that the impact of demand in energy consumption affects mainly the own sector and, consequently, there might be a wide margin for those energy policies designed to save energy in the own sector. Such is the case (see Annex I) of Restaurants and hotels (14) sector, to which we referred before, whose own impact was the 30% of total impact, and the Other non-sales services (18), whose own impact accounts for 28% of their total impact.

From the perspective of production for other sectors, group A, we find the sectors of Agriculture (1), Energy (2) and Non-metal products (4). The total, direct and indirect, impact of these sectors is 11.9% and their direct consumption is 26.2% of the total. A relevant consideration, with regard to the information that can be deduced with respect to the impact on the own sector (see corresponding elements in principal diagonal in Annex I), is that in the three cases this impact is quite high. Indeed, in the case of Agriculture (1) the total impact is 0.041 and the own effect is 0.025, which represents 60.2%; for the energy sector, the total effect is 0.043 and the impact in the own sector is 0.040, thus 93.7% of the total impact corresponds to the own sector; lastly, Non-metal products (4) has a total impact of 0.034 and its own effect is 0.029, which implies an impact on the own sector of 87.9%. Hence, the margin for direct action on these sectors is really large.

The group of sectors B is composed of those that we consider "key" sectors. These would be Domestic transport (15), Chemicals (5), Iron and steel industry and non-ferrous metallurgy (3), Other transport (16), Building (12) and Food (8). Their total effect represents 50.9 % of the whole economy and their share in total energy consumption represents 57.1%. The later two sectors are at the limit between groups D and B. It could be said that in these sectors the total effect is clearly prevalent. The remaining sectors, as can be observed by their situation in the figure, show a greater prevalence as sectors of intermediate goods. The own impact is greater than 80% of the total impact in the case of the sectors of Domestic transport (15), Chemicals (5), Iron and steel industry and non-ferrous metallurgy (3) and Other transport (16), and on the other hand is more than 20% in the case of Building (12) and Food (8). Hence, it is important to establish a clear distinction between these two groups when thinking about energy policy. In addition, even within the first group, Domestic transport should be the object of particular consideration because, especially in the Spanish case, road transport, both of goods and persons, has a very high specific weight. If road private transport had been considered in this analysis, its total impact calculated, would have been considerably greater.

Concluding remarks

The purpose of this paper was not so much to develop a detailed analysis of energy consumption in Spain, as to present a methodological tool for establishing the sectoral relevance of the consumption of final energy and to determine which sectors deserve more attention in the Spanish case. Of course, the approach developed here is more complementary than alternative to others that have been proposed from the input–output perspective in energy economics, as well as in other fields. As for the information, unfortunately, there is no inventory of the consumption of final energy in Spain sufficiently disaggregated and allowing a more detailed classification. Had such an inventory been available, the analysis would have indicated the "key" sectors with greater precision.

Lastly, the analysis should, from an interdisciplinary perspective, include aspects related to the nature of the different sectors themselves. Although it is not the aim of this paper, it is a significant issue for the design of policies aimed at reducing the consumption of energy and, at least, should be undertaken for those that we have defined as "key" sectors.

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ANNEX I

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Total row
1	0.025031	0.000033	0.000023	0.000025	0.000342	0.000146	0.000273	0.022423	0.000598	0.000251	0.000774	0.000321	0.000184	0.008679	0.000052	0.000059	0.000432	0.000944	0.060589
2	0.003069	0.039926	0.002432	0.001103	0.003114	0.003028	0.003604	0.005356	0.001728	0.000792	0.001389	0.005780	0.004840	0.007900	0.003212	0.001249	0.003183	0.006598	0.098303
3	0.000409	0.000275	0.044086	0.000419	0.000692	0.017256	0.015352	0.001278	0.000314	0.000219	0.000997	0.007096	0.001516	0.000988	0.000385	0.000330	0.000933	0.001903	0.094449
4	0.000578	0.000252	0.000852	0.029179	0.002758	0.001866	0.002980	0.003284	0.000437	0.000208	0.000568	0.046158	0.002544	0.003738	0.000361	0.000507	0.004016	0.002322	0.102608
5	0.004612	0.000239	0.001234	0.000749	0.068745	0.002919	0.004342	0.006209	0.004477	0.001533	0.002965	0.005717	0.003795	0.005854	0.000344	0.000269	0.003314	0.007084	0.124401
6	0.000154	0.000105	0.000098	0.000054	0.000102	0.009669	0.001572	0.000425	0.000094	0.000031	0.000107	0.001136	0.000364	0.000310	0.000068	0.000066	0.000238	0.000681	0.015273
7	0.000029	0.000004	0.000013	0.000004	0.000010	0.000039	0.010201	0.000055	0.000013	0.000007	0.000011	0.000058	0.000523	0.000063	0.000140	0.000103	0.000028	0.000315	0.011617
8	0.001419	0.000019	0.000011	0.000012	0.000165	0.000063	0.000087	0.021119	0.000269	0.000029	0.000077	0.000125	0.000056	0.005751	0.000018	0.000033	0.000207	0.000457	0.029916
9	0.000046	0.000007	0.000012	0.000012	0.000064	0.000074	0.000377	0.000102	0.014869	0.000027	0.000169	0.000101	0.000169	0.000275	0.000026	0.000028	0.000071	0.000413	0.016840
10	0.000175	0.000044	0.000067	0.000118	0.000483	0.000402	0.000423	0.001498	0.000354	0.009250	0.000325	0.000649	0.001496	0.000774	0.000105	0.000155	0.001803	0.001565	0.019686
11	0.000217	0.000042	0.000059	0.000062	0.000371	0.000714	0.002380	0.001086	0.000473	0.000091	0.012819	0.001861	0.001004	0.000539	0.000410	0.000105	0.000492	0.000832	0.023558
12	0.000065	0.000080	0.000049	0.000030	0.000071	0.000156	0.000199	0.000193	0.000087	0.000031	0.000073	0.026420	0.000598	0.000949	0.000125	0.000127	0.002124	0.000879	0.032257
13	0.000169	0.000047	0.000228	0.000047	0.000106	0.000411	0.000269	0.000480	0.000181	0.000112	0.000132	0.000579	0.013794	0.001026	0.000216	0.000057	0.000262	0.000326	0.018443
14	0.000042	0.000068	0.000028	0.000037	0.000089	0.000191	0.000229	0.000178	0.000135	0.000031	0.000099	0.000368	0.000116	0.022324	0.000055	0.000100	0.000320	0.000427	0.024837
15	0.004629	0.000969	0.002844	0.001406	0.003862	0.006267	0.009563	0.014741	0.003444	0.001433	0.003174	0.023383	0.004390	0.013011	0.102171	0.001402	0.006015	0.011932	0.214636
16	0.000688	0.000450	0.000389	0.000260	0.000647	0.001109	0.001642	0.002211	0.000755	0.000363	0.000629	0.002559	0.001284	0.001639	0.005491	0.051906	0.001721	0.001975	0.075718
17	0.000178	0.000101	0.000098	0.000064	0.000220	0.000455	0.000616	0.000503	0.000212	0.000094	0.000218	0.001071	0.001122	0.000872	0.000152	0.000209	0.012668	0.001823	0.020676
18	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.016192	0.016192
Total column	0.041511	0.042660	0.052523	0.033581	0.081842	0.044766	0.054109	0.081141	0.028441	0.014501	0.024528	0.123382	0.037793	0.074694	0.113330	0.056704	0.037826	0.056666	1.000000