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ENERGY INTENSITY IN ROAD FREIGHT TRANSPORT OF HEAVY GOODS VEHICLES IN SPAIN

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ABSTRACT

This paper examines the factors that have influenced the energy intensity trend of the Spanish road freight transport of heavy goods vehicles over the period 1996–2012. This article aims to contribute to a better understanding of these factors and to inform the design of measures to improve energy efficiency in road freight transport. The paper uses both annual single-period and chained multi-period multiplicative LMDI-II decomposition analysis. The results suggest that the decrease in the energy intensity of Spanish road freight in the period is explained by the change in the real energy intensity index (lower energy consumption per tonne-kilometre transported), which is partially offset by the behaviour of the structural index (greater share in freight transport of those commodities the transportation of which is more energy intensive). The change in energy intensity is analysed in more depth by quantifying the contribution of each commodity through the attribution of changes in Divisia indices.

Keywords: energy intensity, road freight transport, LMDI, Divisia index decomposition

1. INTRODUCTION

In recent decades there has been growing concern to achieve more efficient energy use (IEA, 2013, 2014). The interest in improving energy efficiency lies in the reduction of energy costs, as well as lower energy consumption and the reduction of greenhouse gas emissions and other air pollutants resulting from fuel consumption. An in-depth analysis of the determinants of change in energy consumption is therefore important to facilitate the implementation of policies that promote savings, more efficient energy use and lower environmental impacts.

Between 1996 and 2012, greenhouse gas emissions showed a different behaviour in Spain in relation to the European Union (EU). Spanish emissions increased by 8.2% over the period compared to a 15.2% reduction in the 28 EU member states (equivalent CO_2 emissions of the six gases covered by the Kyoto Protocol, European Commission, 2014).[1] The transport sector has significantly contributed to this undesirable growth in emissions. The Spanish transport sector's emissions increased by 7.3% over the period compared to the 3.3% increase in the EU 28, contributing to 23.7% of total emissions in 2012, of which 92.1% corresponds to road transport. The upward trend in emissions in the Spanish transport sector is explained by a 18.5% rise in energy consumption over the period, reaching 40.1% of total final energy consumption in 2012 (European Commission, 2014). These results show that between 1996 and 2012, the Spanish transport sector was unable to reverse the upward trend in terms of energy consumption observed since the 1970s (Stead, 2001), which explains the difficulty in reducing the related greenhouse gas emissions.

Numerous investigations have examined the role of the transport sector in final energy consumption and/or related emissions. Part of this literature employs IPAT descriptive models (the IPAT equation states that environmental impact (I) is the product of population (P), affluence (A), and technology (T)) (Ehlrich and Holdren, 1971, 1972). Based on these models, the

[1] While some increase in emissions was expected, as the target for Spain under the Kyoto Protocol for 2008–2012 with respect to 1990 was an increase of 15%, there was an increase of 20.1% in the whole period 1990–2012.

International Energy Agency has developed the ASIF equation, where emissions are expressed as the product of different factors to study the drivers of any pollutant's emissions in the transport sector. These factors are total transport activity (A), structure, measured as the share of transport mode in total activity (S), energy intensity of every transport mode (I), and fuel used by transport mode (F). Following this line, two distinct activities are distinguished: passengers and freight. It should be added that some investigations include parametric decomposition analyses, from traditional methods such as the Laspeyres index (Millard-Ball and Schipper, 2010) to more recent and improved methods, such as the log mean Divisia Index (LMDI) (Sorrell et al., 2009, 2012).

Concerning road freight transport, a number of works should be pointed out. Kamakaté and Schipper (2009) study the energy use of road freight transport in Australia, France, Japan, the United States and the United Kingdom between 1973 and 2005. They conclude that reductions in trucking energy use will be achieved not only through fuel economy of vehicles but also with better logistics and driving. Vanek and Campbell (1999) explore energy consumption and energy intensity trends of road transport for 14 commodity groups between 1985 and 1995 in the United Kingdom. They note the growth in length and complexity of supply chains as the main driver of increasing freight energy consumption and also identify some of the determinants of energy intensity such as the mix of vehicles used and average payload. Vanek and Morlok (2000) investigate the change in energy consumption in freight transport in the United States disaggregated by commodities and transport modes. They suggest that the techniques based on modal transport will not reverse the rapidly growing energy use in the US freight transport, and conclude that a commodity-based approach is needed to make mode-based techniques more effective and to introduce new techniques, such as length of haul of the total demand for tonne-kilometre of freight. Sorrell et al. (2009, 2012) estimate the relative contribution of ten key ratios plus GDP to the change in UK road freight energy use between 1989 and 2004. They discover a relative but not absolute decoupling of road freight energy consumption from GDP, mainly explained by the declining value of manufactured goods relative to GDP, and also by reductions in the average payload weight, the amount of empty running and the fuel use per vehicle-kilometre.

Changes in energy consumption and related emissions in the transport sector in Spain are investigated by Mendiluce and Schipper (2011). They analyse the energy consumption and emissions trends for the Spanish transport sector between 1990 and 2008 differentiating between passenger and freight transport modes. These authors find out that both activities have increased over the period and that the increasing trend in energy consumption and emissions will continue if there are not policies aimed to reduce transport activity. Pérez Martínez (2009) reviews certain indicators of efficiency and performance in the Spanish road freight transport between 1997 and 2003. He concludes that energy and environment efficiencies have poorly improved during the period. Pérez Martínez (2010) investigates the energy consumption of freight transport and related emissions for the period 1990–2007 and projections for 2025. He determines that the increasing growth in energy use will not stop unless there were significant reductions in the energy intensities of road freight, a change in the modal share, and an improvement in the average performance of road diesel vehicles. Finally, Pérez Martínez and Monzón de Cáceres (2008) compare the change in environmental indicators, such as energy consumption and carbon dioxide emissions, in the Spanish transport sector with EU countries for 1988 and 2006. They show that emissions growth in Spain was twice as that of EU, due to higher weight of more inefficient modal transport and to the fact that the improvements in energy efficiency achieved through more efficient technologies had been offset by increasing activity and more powerful vehicles.

In this paper, we focus on the study of the energy intensity of road freight transport, its progression and its determinant factors. Moreover, the analysis is disaggregated by commodities. While most studies in the mentioned literature focus on energy consumption, this investigation deepens understanding of one of its main components, energy intensity, a variable that is key in achieving a more efficient use of energy in transport. The main contribution of this paper is the application of decomposition analysis to energy intensity in the road freight transport and the in-depth study of its two determinant factors defined in this paper through commodity approach. These factors are the real energy intensity index (measured as energy consumption per tonne-kilometre transported) and the structural index (the relative change in the composition of road freight transport). Thereby, this article aims to contribute to a better understanding of the changes in the energy intensity of road freight transport. The analysis relates to Spanish road freight transport of heavy goods vehicles over the period 1996–2012. It adapts the ASIF methodology and is further enhanced by applying annual single-period and chained multi-period multiplicative LMDI-II decomposition analysis. To expand the results of the decomposition analysis, an extension is also applied: the attribution of changes in Divisia indices. This novel methodology precisely identifies the degree to which each commodity group has contributed to the change in energy intensity through the real energy intensity index and through the structural index. The results can inform the design of policies the purpose of which is to achieve more efficient energy use in road freight transport.

The rest of the paper is organised as follows. Section 2 discusses the data and estimation methodology. Section 3 describes the results of energy intensity analysis (aggregated and by commodity). Section 4 presents the results of the decomposition analysis and its extension. Section 5 summarises and concludes the paper.

2. DATA AND METHODOLOGY

This section presents the data employed, detailing the data sources and the estimations made for this study (Subsection 2.1), and the methodology applied in our research. As regards the methodology, it, first, describes the road freight energy intensity identity employed in our analysis, which disaggregates it as the product of two factors (Subsection 2.2). Then, it shows the methodology applied to decompose energy intensity changes into structural and real energy intensity effects (Subsection 2.3). Finally, it describes the methodology used to attribute the changes in energy intensity to structural and real energy intensity indices, by commodity groups (Subsection 2.4).

2.1. DATA

The database used is that of the Spanish Continuing Survey of Road Goods Transport (Encuesta Permanente del Transporte de Mercancías por Carretera, EPTMC) for the years 1996–2012, a survey of road freight carried out by the Ministry of Public Works and Transport (Ministerio de Fomento, 2013). The main objective of this survey is to investigate the transport operations of heavy goods vehicles to measure the extent of the sector's activity in Spain. The survey is continuous and registers the movements of Spanish heavy goods vehicles with a gross weight in excess of 3.5 tonnes or maximum permissible laden weight above 6.0 tonnes. All operations performed by these vehicles are investigated both nationally and abroad. The survey collects information on origin, destination, distance of the operation and vehicle characteristics for different commodity groups, which follow the NST/R nomenclature (standard goods classification for transport statistics) disaggregated to two digits.

Table 1 summarises the technical characteristics of heavy goods vehicles which define different types of vehicles.

[TABLE 1 ABOUT HERE]

It should be noted that until 2002 the EPTMC did not collect data on operations within the same municipality. For this reason and to obtain a homogeneous set of data, this analysis only includes operations between municipalities, which accounted for at least 97.1% of total road freight activity in the period considered.

To conduct the decomposition analysis of road freight energy intensity, we require annual data on energy consumption and activity disaggregated by commodity groups during the period 1996–2012. The EPTMC directly provides data on freight transport by commodity groups, whereas the data on the energy consumption of freight transport by commodity groups need to be estimated. Then, the energy consumption of freight transport of commodity group c in year t ($E_{c,t}$) is calculated as follows:[2]

$$E_{c,t} = \sum_k E_{c,k,t} = \sum_k VKM_{c,k,t} \, AF_k \, e \tag{1}$$

where $VKM_{c,k,t}$ is the annual distance travelled measured in kilometres by vehicle of type k in year t when transporting commodity group c, AF_k is the average annual fuel consumption per distance of vehicle type k, and e is the conversion factor —energy/fuel— provided by the Spanish Energy Efficiency Agengy (Instituto para la Diversificación y Ahorro de Energía, IDAE, 2010b).

Although the EPTMC directly provides $VKM_{c,k,t}$, a problem arises when the activity is disaggregated by commodity group: empty running is classified as another commodity group. That is, there is no information concerning the correspondence between the loaded distance travelled for commodity groups and the amount of empty running. However, as loaded and empty running operations are recorded for each vehicle, the amount of empty running travelled by vehicle has been assigned proportionally to the loaded distance travelled by the vehicle in transporting each commodity group.

The allocation of fuel consumption per kilometre AF_k to each type of vehicle is made taking into account: i) the guidelines provided by IDAE (2006), which contain the general reference standards of efficiency in the fuel consumption of the different fleet vehicles; ii) the average fuel consumption per vehicle indicated in Ministerio de Fomento (2010a). Once the assignment was completed following equation (1), from the resulting total annual fuel consumption of heavy goods vehicles, we calculated the average annual fuel consumption for each year of the period 1996–2012 and we checked that it corresponded to that published by IDAE (2010a), (Table 7). It

[2] This analysis only considers the direct consumption of final energy required for freight transport and does not take into account indirect energy consumption (in the manufacture of vehicles, infrastructure and its maintenance, decommissioning and recycling of vehicles, or in the extraction, refining and distribution of fuel).

could be noted that the deviation of estimated average fuel consumption with respect to IDAE (2010a) is below 1%, with the exception of years 1996 and 1997 (below 2% and 1.25% respectively).

2.2. THE ROAD FREIGHT ENERGY INTENSITY IDENTITY

In this subsection we define the identity that will be employed for our decomposition analysis. The aim of this research is to analyse the energy intensity of road freight. Therefore, in contrast to the ASIF equation described in the introduction, transport mode and fuel are not the variables used to disaggregate the analysis. Instead, the disaggregation is carried out by commodity group (c).

The energy consumption of road freight can be disaggregated as follows:

$$E_t = \sum_{c=1}^{n} E_{c,t} = \sum_{c=1}^{n} TKM_t \; S_{c,t} \; I_{c,t} \tag{2}$$

where E_t is the energy consumption of road freight expressed in megajoules in year t, $E_{c,t}$ is the the energy consumption of freight transport of commodity group c estimated following equation (1), TKM_t is the activity of road freight measured in tonne-kilometre, $S_{c,t}$ represents the share of transport of commodity group c in road freight activity ($\frac{TKM_{c,t}}{TKM_t}$), and $I_{c,t}$ is the energy intensity of transport of commodity group c expressed in megajoules per tonne-kilometre ($\frac{E_{c,t}}{TKM_{c,t}}$).

Thus, the aggregate energy intensity in year t, I_t, can be expressed as:

$$I_t = \sum_{c=1}^{n} \frac{E_{c,t}}{TKM_t} = \sum_{c=1}^{n} S_{c,t} I_{c,t} \tag{3}$$

2.3. THE MULTIPLICATIVE LOG MEAN DIVISIA INDEX DECOMPOSITION

This subsection explains the methodology applied to decompose energy intensity changes into structural and real energy intensity effects, which are the changes associated to the variations in the two factors of the identity of equation (3). The Index Decomposition Analysis (IDA) technique is widely used in energy studies. The object of IDA is to disaggregate the changes in the variable to be analysed into different explanatory effects. In the case of energy consumption, the decomposition usually has three effects: scale, structure and intensity. To study the impact of structural change in the road freight transport sector in Spain, we apply the decomposition method of the logarithmic mean Divisia index in its multiplicative form (M-LMDI-II) in relation to energy intensity rather than to energy consumption. Although the analysis of energy consumption is relevant, we focus the analysis on energy intensity and not on energy consumption to avoid the problem that appears when considering an extended period of analysis in which activity grows at a high rate: the scale effect estimated tends to be very significant and much higher than the other two effects (Ang, 1994). Thus, energy intensity is the most appropriate study variable in this case.

The energy intensity decomposition of this study comprises two indices: i) a structural index (SE), which provides a measure of change in energy intensity due to the relative change in the share of the commodity groups ($S_{c,t}$) that are more energy intensive in terms of transport; ii) a real energy intensity index (EI), defined as an indicator of energy intensity change due to the variation in the apparent energy efficiency of road freight transport in the transportation of the different commodities ($I_{c,t}$), the variation of which may be due to a change in fuel consumption per tonne-kilometre, traffic, and driving conditions or road conditions, among other factors.

The choice of the M-LMDI-II method is due to its theoretical foundation and its desirable properties (Ang, 2004).[3] The properties of the various decomposition methods are analysed in,

[3] First, it is a perfect decomposition method; that is, residual terms do not appear in the results, so it overcomes the test of reversibility. Second, the test shows robustness to the value 0 as it works properly when replaced by a very small value. Third, it passes the test of reversibility in time, that is the results are identical if the decomposition is carried out forward or backward in time. Fourth, it overcomes the aggregation test, so it is consistent in aggregating

for example, Ang and Zhang (2000), Sun and Ang (2000), Lenzen (2006) and Ang and Liu (2007).

Through the yearly single-period decomposition, the change in energy intensity (3) between two consecutive years can be expressed as $\frac{I_t}{I_{t-1}}$ and can be decomposed into a real energy intensity index and a structural index as follows:

$$\frac{I_t}{I_{t-1}} = \frac{IE_t}{IE_{t-1}} \times \frac{SE_t}{SE_{t-1}} \tag{4}$$

According to the M-LMDI-II, the formulae of the real energy intensity index and the structural index are respectively given by:

$$\frac{IE_t}{IE_{t-1}} \equiv exp\left(\sum_{c=1}^{n} w_c \, ln \frac{I_{c,t}}{I_{c,t-1}} \right) \tag{5}$$

$$\frac{SE_t}{SE_{t-1}} \equiv exp\left(\sum_{c=1}^{n} w_c \, ln \frac{S_{c,t}}{S_{c,t-1}} \right) \tag{6}$$

where $w_c = \frac{L\left(\frac{E_{c,t}}{E_t}, \frac{E_{c,t-1}}{E_{t-1}}\right)}{\sum_{c=1}^{n} L\left(\frac{E_{c,t}}{E_t}, \frac{E_{c,t-1}}{E_{t-1}}\right)}$ and $L(a,b) = \begin{cases} \frac{(a-b)}{(ln\, a - ln\, b)}, & a \neq b \\ a, & a = b \end{cases}$

being $L(a, b)$ the logarithmic average of two positive numbers a and b.

In chained multi-period decomposition, changes in Divisia energy intensity index are described as:

$$\frac{\mathrm{I_T}}{\mathrm{I_0}} = \prod_{\mathrm{t}=1}^{\mathrm{T}} \frac{\mathrm{I_t}}{\mathrm{I_{t\text{-}1}}} = \frac{\mathrm{IE_T}}{\mathrm{IE_0}} \times \frac{\mathrm{SE_T}}{\mathrm{SE_0}} \tag{7}$$

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the results of the decomposition by subgroup, regardless of how these subgroups are defined. Fifth, it is easily applied and its results are easily interpreted. Sixth, it is adaptable, which means that it can be applied even when data base contains zeros, negative values and a high dispersion. Also, the absence of negative data in the database does not necessitate the use of alternative methods related to the Laspeyres index. Finally, the results obtained in the multiplicative version of this method are related to those obtained in the additive version through a simple formula.

where:

$$\frac{IE_T}{IE_0} = \prod_{t=1}^{T} \frac{IE_t}{IE_{t-1}} \tag{8}$$

$$\frac{SE_T}{SE_0} = \prod_{t=1}^{T} \frac{SE_t}{SE_{t-1}} \tag{9}$$

Expressions (8) and (9) are the cumulative products between 0 and T of the single-period real energy intensity and structural indices, respectively.

2.4. ATTRIBUTION OF CHANGES IN THE INDICES BY COMMODITY GROUPS

This subsection explains the methodology used to attribute the changes in energy intensity and its two effects, structural and real energy intensity indices, by commodity groups. The methodology described in Choi and Ang (2012) attributes the changes in the Divisia real energy intensity index to different sources associated with such changes. We apply this methodology to the real energy intensity index and the structural index. This allows us to obtain a detailed analysis of the contribution of each commodity group in the change in the two indices, taking into account that both determine the changes in energy intensity.

The methodology, both for the single-period attribution analysis and for the multi-period attribution analysis, is based on the transformation of a geometric mean index, as is the case of M-LMDI-II, into an arithmetic mean index. Following Choi and Ang (2012), the formulae for the single-period attribution of the real energy intensity index and the structural index are given by:

$$\frac{IE_t}{IE_{t-1}} - 1 = \sum_{c=1}^{n} s_c^I \left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right) \tag{10}$$

$$\frac{SE_t}{SE_{t-1}} - 1 = \sum_{c=1}^{n} s_c^S \left(\frac{S_{c,t}}{S_{c,t-1}} - 1\right) \tag{11}$$

Thus, $s_c^I\left(\frac{I_{c,t}}{I_{c,t-1}}-1\right)$ and $s_c^S\left(\frac{S_{c,t}}{S_{c,t-1}}-1\right)$ correspond, respectively, to the contribution of road freight of commodity group c to the change in the real energy intensity index and to the change in the structural index between two consecutive years, where:

$$s_c^I = \frac{\frac{w_c}{L\left(I_{c,t},I_{c,t-1}\frac{IE_t}{IE_{t-1}}\right)}I_{c,t-1}}{\sum_{k=1}^{n}\frac{w_k}{L\left(I_{k,t},I_{k,t-1}\frac{IE_t}{IE_{t-1}}\right)}I_{k,t-1}} \qquad (12)$$

$$s_c^S = \frac{\frac{w_c}{L\left(S_{c,t},S_{c,t-1}\frac{SE_t}{SE_{t-1}}\right)}S_{c,t-1}}{\sum_{k=1}^{n}\frac{w_k}{L\left(S_{k,t},S_{k,t-1}\frac{SE_t}{SE_{t-1}}\right)}S_{k,t-1}} \qquad (13)$$

Following Choi and Ang (2012), for the multi-period attribution analysis, the formulae to disaggregate the real energy intensity index and the structural index are:

$$\frac{IE_T}{IE_0}-\ 1=\sum_{c=1}^{n}\sum_{t=1}^{T}\frac{IE_{t-1}}{IE_0}s_{c,t-1,t}^I\left(\frac{I_{c,t}}{I_{c,t-1}}-1\right) \qquad (14)$$

$$\frac{SE_T}{SE_0}-\ 1=\sum_{c=1}^{n}\sum_{t=1}^{T}\frac{SE_{t-1}}{SE_0}s_{c,t-1,t}^S\left(\frac{S_{c,t}}{S_{c,t-1}}-1\right) \qquad (15)$$

where:

$$s_{c,t-1,t}^I = \frac{\frac{w_{c,t-1,t}}{L\left(I_{c,t},I_{c,t-1}\frac{IE_t}{IE_{t-1}}\right)}I_{c,t-1}}{\sum_{k=1}^{n}\frac{w_{k,t-1,t}}{L\left(I_{k,t},I_{k,t-1}\frac{IE_t}{IE_{t-1}}\right)}I_{k,t-1}} \qquad (16)$$

$$s_{c,t-1,t}^S = \frac{\frac{w_{c,t-1,t}}{L\left(S_{c,t},S_{c,t-1}\frac{SE_t}{SE_{t-1}}\right)}S_{c,t-1}}{\sum_{k=1}^{n}\frac{w_{k,t-1,t}}{L\left(S_{k,t},S_{k,t-1}\frac{SE_t}{SE_{t-1}}\right)}S_{k,t-1}} \qquad (17)$$

Equation (14) expresses the percentage change in the real energy intensity index between 0 and T as the cumulative sum of annual percentage changes evaluated at year 0 through IE_{t-1}/IE_0. In parallel, equation (15) shows the percentage change in the structural index between 0 and T. Therefore, the contribution of road freight transport in commodity group *c* in the change of the real energy intensity index between *t-1* and *t* corresponds to the value $\frac{IE_{t-1}}{IE_0} s^{I}_{c,t-1,t} \left(\frac{I_{c,t}}{I_{c,t-1}} - 1\right)$ evaluated at year 0, while $\frac{SE_{t-1}}{SE_0} s^{S}_{c,t-1,t} \left(\frac{S_{c,t}}{S_{c,t-1}} - 1\right)$ determines the contribution of road freight transport in commodity group c in the change of the structural index between *t-1* and *t* and evaluated at year 0.

3. RESULTS

3.1. ENERGY INTENSITY TREND

During the period 1996–2012, the strong increase in Spanish road freight energy consumption is mainly explained by the activity's significant growth, which increased by 84.7% measured in millions of tonne-kilometre (TKM). The activity also grew faster than the whole economy as GDP increased by 43.9% over the period, which explains its greater share in final energy consumption and in related emissions in Spain.

Regarding modal shares in freight transport in Spain over the period 1996–2012, it should be noted that road freight grew by 95% (199,205 millions of TKM in 2012 compared to 102,167 millions of TKM in 1996), whereas the alternative, rail transport, fell by 10.3% (from 11,100 millions of TKM in 1996 to 9,957 millions of TKM in 2012). Thus, road freight accounted for 95.2% of total freight activity in Spain in 2012.[4]

[FIGURE 1 ABOUT HERE]

Figure 1 shows a change in the trend of road freight as a result of the beginning of the economic crisis in Spain in 2008: activity grew by 153.4% from 1996 to 2007 and decreased by 23% from 2007 to 2012. Energy consumption for road freight was also affected by the economic crisis:

[4] In Spain, the total volume of road freight transport represented 84% of freight transport in 2007, railway transport 1% and maritime transport 15% (that includes loading and unloading), according to Eurostat (2013) data.

over the period 1996 to 2012 it rose by 89.7% while at its peak in 2007, the increase was 140.7%.

[FIGURE 2 ABOUT HERE]

The energy intensity for road freight in Spain dropped by 1.9%, from 1.05 MJ/TKM in 1996 to 1.03 MJ/TKM in 2012. Figure 2 shows this variable's behaviour over time. Its progression is somewhat erratic. During the years of economic crisis, the decrease in energy intensity was because energy consumption in road freight fell faster than road freight activity. During the period of economic expansion, energy intensity reduction was because road freight activity grew faster than energy consumption in road freight.

Table 2 summarises the results of computing equation (3) for energy intensity, aggregated and by commodity group, and the share of commodity groups in road freight in Spain in the years 1996 and 2012.

[TABLE 2 ABOUT HERE]

These first results point to a change in energy intensity as well as in structure for road freight activity over the period 1996–2012 in Spain. In particular, the energy intensity of different commodity groups reveals a distinct pattern. Energy intensity increased considerably in the case of the transport of “Coal chemicals, tar”, “Textiles, textile articles and man-made fibres, other raw animal and vegetable materials”, and “Wood and cork”. However, it decreased especially in the case of the transport of “Paper pulp and waste paper”, “Transport equipment, machinery,…”, and “Live animals, and sugar beet”. In 2012, the disparity in energy intensities, which ranged from 0.65 MJ/TKM for “Non-ferrous ores and waste” to 1.47 MJ/TKM for “Live animals and sugar beet”, was lower than the disparity in 1996 as shown by Figure 3.

[FIGURE 3 ABOUT HERE]

On the other hand, shifts in the share of commodity groups mark a significant structural change in transport activity. In fact, the importance of the transport of the commodities “Foodstuff and animal fodder” and “Potatoes, other fresh or frozen fruits and vegetables” increased notably, whereas the weight of “Crude and manufactured minerals”, “Cement, lime and manufactured building materials”, “Metal products”, and “Chemicals other than coal chemicals and tar” was reduced in overall activity.

[TABLE 3 ABOUT HERE]

Taking into account the structural change, the data obtained from the EPTMC indicate that the amount of empty running with respect to total distance travelled decreased over the period considered, which represented a relative improvement in the logistics of the activity. In short, 29.1% of the total distance travelled by heavy goods vehicles corresponded to empty running in 1996, whereas this was reduced to 22.9% in 2012. That is, whereas empty running increased by 53.9%, the loaded distance travelled increased by 99.0% over the period.

3.2. DECOMPOSITION ANALYSIS RESULTS

3.2.1. M-LMDI-II DECOMPOSITION

The M-LMDI–II decomposition results are summarised in Table 4, which shows the results of computing equations (4), (5) and (6) for the yearly single-period decomposition and equations (7), (8) and (9) for the chained multi-period decomposition. Through the single-period decomposition, it can be seen that the progression of energy intensity of road freight activity was somewhat erratic over the period considered. In some years it increased, as illustrated by the positive contribution to this increase of both the energy intensity index and structural index for the years 1999, 2001, 2005, 2007, 2009 and 2012. However, in other years (1997, 1998, 2006, 2008 and 2011), energy intensity decreased as both indices contributed to this decrease.

However, through the multi-period decomposition analysis, it can be seen that the real energy intensity index contributed to energy intensity reduction by 3.0% over the period. In contrast, the structural index contributed to increasing energy intensity by 1.1% during the same period. The combination of these two effects led to a 1.9% decrease in energy intensity from 1996 to 2012.

[TABLE 4 ABOUT HERE]

The implications of the results are immediate. The energy intensity reduction in road freight in Spain is the result of the positive contribution of the real energy intensity index. That is, greater apparent energy efficiency in road freight (lower fuel consumption per tonne-kilometre). However, this was partially offset by the negative contribution of the structural index: the commodity groups which are more energy intensive in their transportation increase their share in the activity. Thus, the multi-period decomposition analysis shows that the real energy intensity index has negative cumulative growth rates, which translate into an improvement in energy efficiency. Similarly, except for the years 1997 and 1998, the structural index has positive cumulative growth rates which contributed, in turn, to worsening energy efficiency. As the negative growth rates of the real energy intensity index were superior to the positive growth rates of the structural index, energy intensity decreased over the period.

It should also be noted that the somewhat erratic behaviour of energy intensity corresponds to the development shown by the real energy intensity index throughout the period, while the structural index shows less variability. In particular, the negative real energy intensity index for the years 2004 and 2009 changed the progression of energy intensity (Figure 4). To obtain more clues to the factors behind the contribution of both effects and to establish which policies could improve energy intensity for road freight in the future, we proceed to decompose these effects into the contribution of each commodity group.

[FIGURE 4 ABOUT HERE]

3.2.2. RESULTS OF ATTRIBUTION OF CHANGES IN DIVISIA TO THE REAL ENERGY INTENSITY INDEX AND THE STRUCTURAL INDEX

Table 5 summarises the results of multi-period attribution analysis of energy intensity for the real energy intensity index and the structural index in the period 1996–2012, obtained from the computation of equations (14) and (15). The last row of the table shows the contribution to the cumulative percentage change in energy intensity of the real energy intensity index and the structural index over the period. The method attributes this change quantitatively to the transportation of each of the 24 commodity groups. Regarding the real energy intensity index, it can be said that the commodity groups “Foodstuff and animal fodder”, and “Transport equipment, machinery, …” determine almost entirely the positive development of the real energy intensity index between 1996 and 2012.

Regarding the structural index, it can be seen that the worsening in energy intensity derived from this index is mainly due to the following commodity groups: “Potatoes, other fresh or frozen fruits and vegetables”, “Foodstuff and animal fodder”, and “Miscellaneous articles”. This is despite the positive contribution of the commodity groups “Crude and manufactured minerals”, and “Cement, lime and manufactured building materials”.

[TABLE 5 ABOUT HERE]

The combination of both indices provides the contribution of each commodity group to the progression of energy intensity in road freight in the period 1996–2012. Thus, the commodity groups “Cement, lime and manufactured building materials”, and “Crude and manufactured minerals” contribute significantly to the reduction of energy intensity in road freight.

However, three commodity groups with a significant share in total activity, “Potatoes, fresh or frozen fruits and vegetables”, “Foodstuff and animal fodder”, and “Miscellaneous articles”, prevented further contraction in energy intensity over the period analysed. In the first case, “Foodstuff and animal fodder”, despite having reduced real energy intensity in the period considered (positive real energy intensity index), increased its relative weight in total activity (negative structural index) in such a way that the second index dominates the first. In the second two cases, “Potatoes, fresh or frozen fruits and vegetables” and “Miscellaneous articles”, both increased in terms of real energy intensity and their relative weight in total activity.

Taking into account the above and in relation to the study of the somewhat erratic behaviour of energy intensity, the high variability of the real energy intensity index may be explained by the commodity groups “Foodstuff and animal fodder” and “Miscellaneous articles”. Specifically, both experienced a strong growth in the real energy intensity index in 2004 and 2009. Moreover, a more detailed analysis of the progression of the real energy intensity index in 2004 and 2009 reveals that the commodity groups “Potatoes, fresh or frozen fruits and vegetables”, and “Leather, textiles, clothing and other manufactured articles” should also be considered. Similarly, the commodity group “Transport equipment, machinery, …” should also be taken into account for 2009 (Table 8) .

To examine what factors explain the results of the real energy intensity index for the commodity groups indicated in years 2004 and 2009, two key performance factors of the activity were analysed: transport content and transport efficiency. In 2004 and 2009, both key factors, transport content (distance travelled per tonne transported) and transport efficiency (tonnes carried per vehicle) worsened considerably.[5] In short, the negative development of the real energy intensity index in 2004 and 2009 is explained because in transporting these commodity groups, heavy goods vehicles carried fewer tonnes and travelled more kilometres per tonne transported.

[TABLE 6 ABOUT HERE]

[5] Regarding the transport content factor, the commodity group “Miscellaneous articles” is an exception in 2004 and the commodity groups “Potatoes, other fresh or frozen fruits and vegetables” and “Leather, textiles, clothing and other manufactured articles” are the exceptions in 2009.

4. DISCUSSION

The energy intensity of road freight transport of heavy goods vehicles dropped by 1.9% in Spain over the period 1996–2012. The improvement in energy efficiency was very modest in relation to the 89.7% increase in the energy consumption of road freight transportation in the same period. This poor improvement in energy intensity of road freight transport of heavy goods vehicles is in consonance with the findings of Pérez Martínez (2009) and Mendiluce and Schipper (2011).

The decomposition analysis of energy intensity change shows that the positive result in energy intensity progression was due to the behaviour of the real energy intensity index, due to the lower energy consumption per tonne-kilometre. This was partially offset by the bad behaviour of the structural index, as more energy intensive commodity groups increased their relative share in total activity. Moreover, the results of the decomposition analysis show that the decrease in energy intensity over the period was not constant but somewhat erratic. This behaviour was due to the instability shown by the real energy intensity index, whereas the structural index presented little variability.

The attribution analysis of energy intensity shows that not all commodity groups participated positively in the reduction nor to the same degree over the period of time analysed. Thus, the commodity groups that contributed significantly to the reduction of energy intensity in road freight were “Crude and manufactured minerals”, and “Cement, lime and manufactured building materials”. An important remark is that these two commodity groups are directly related to construction, a sector seriously affected by the economic crisis in Spain. In contrast, “Foodstuff and animal fodder”, “Potatoes, fresh or frozen fruits and vegetables”, and “Miscellaneous articles” were the commodity groups that prevented greater contraction in energy intensity over the period. It is worth to note that the commodity groups “Foodstuff and animal fodder”, and “Potatoes, fresh or frozen fruits and vegetables” are directly related to the food industry. The analysis has shown that heavy goods vehicles, when transporting these commodity groups, carried fewer tonnes and travelled more kilometres per tonne transported, i.e. the logistics seem to not work correctly. Furthermore, the trend in the three last commodity groups also helps to explain to a great extent the somewhat erratic movement of the real energy intensity index.

Lastly, our estimation of empty running disaggregated by commodity group (explained in Subsection 2.1) could have affected somehow the results obtained. In the same way, the allocation of vehicle fuel consumption according to the guidelines of efficiency provided by IDAE (2010a) could also have influenced the results.

5. CONCLUSIONS AND POLICY IMPLICATIONS

The substantial increase in the energy consumption of freight transport in Spain during the period 1996–2012 is explained by the strong growth in activity. Road freight activity was clearly primarily responsible for this increase, accounting for between 90% and 95% of domestic freight transport over the period.

Investigating the energy intensity of transport, its trend and its determinant factors, the real energy intensity index and the structural index, helps to understand the behaviour of one key component of energy consumption. This article aims to contribute to a better understanding of the factors behind the change in energy intensity in relation to road freight, which can inform the design of measures to achieve greater energy efficiency in the sector. The use of the M-LMDI-II decomposition analysis to examine energy intensity complements the literature that to date has focused mainly on the study of energy consumption in road freight. Similarly, expanding the study through considering the attribution of changes in the Divisia index probes the results in greater depth and shows how each commodity group has participated in changes in energy intensity.

The greater importance of the real energy intensity index in explaining changes in energy intensity and the fact that the structural index depends on the specialization of the economy, reinforces the idea that the policies should aim to implement measures leading to a further reduction in the real energy intensity index. These measures should not only consist of the gradual replacement of the fleet with more energy efficient vehicles, and/or the introduction of higher quality fuels, or more generally, of adequate infrastructure and efficient driving. The Spanish Government applied two plans according to these measures during the last decade: the Strategic Plan for Road Freight Transport (Plan Estratégico para el Transporte de Mercancías por Carretera, PETRA) (Ministerio de Fomento, 2001) in the period 2001–2006 and the Strategic Action Plan for Road Freight Transport (Plan Estratégico de Actuación para el Transporte de Mercancías por Carretera, PETRA II) (Ministerio de Fomento, 2008) in 2006–2011. The moderate decrease in energy intensity over the period shows the limited success of these two plans. Therefore, other factors should also be considered to achieve greater energy efficiency.

The change in the structural index shows how the success of measures to achieve more efficient energy use in road freight transport depends on the extent to which the composition of commodity groups is properly taken into account. Thus, measures designed to achieve greater energy efficiency are even more necessary in a context in which the more energy intensive commodity groups increase their share in transport activity, as was the case in Spain during the period 1996–2012. In this context, and under a scenario where road freight activity has taken advantage over other transport modes over the period, it would be advisable that authorities promote the use of alternative modes of freight transport as rail. This seems to be the strategy carried out recently by the Spanish Government, which has set up the Strategic Plan for the Promotion of Rail Freight in Spain (Plan Estratégico para el Impulso del Transporte Ferroviario de Mercancías en España, Ministerio de Fomento, 2010b) for the period 2010–2020. The objective of this plan is to promote a greater rail use in the Spanish freight transport, increasing its share (measured in tonnes kilometres) from 4.1% in 2010 to 8%–10% in 2020.

The results of the attribution of the real energy intensity index and of the structural index by commodity group suggest the need to design measures that take into account the commodity group being transported. This research has demonstrated the relevance to take this into account, as each commodity group is involved to a different degree and with different sign in the reduction of energy intensity. Regarding the real energy intensity index, it is important to improve the logistics, i.e. to reduce empty running, get better transport content and transport efficiency, and to achieve the suitable mix of vehicles used, in line with the measures suggested by Kamakaté and Schipper (2009) and Vanek and Campbell (1999). We also agree, as suggested by Vanek and Morlok (2000), that authorities should develop these measures paying special attention to those commodity groups that have revealed bad behaviours in the real energy intensity index. In relation to the structural index, the commodity groups which are more energy intensive in their transport should reduce their share in road freight. Policy makers should design policies aimed to achieve a greater use of alternative transport modes such as rail, particularly in the case of the transport of these commodity groups.

Finally, the real energy intensity index does not to show a clear trend, due to its somewhat erratic evolution, specially because of its trend change in years 2004 and 2009. It is worth to note that there are not official data of fuel consumption. The methodology used to estimate fuel consumption was to assign an average consumption by vehicle type (a fixed value over the period provided by IDAE, 2006, and Ministerio de Fomento, 2010a), as it was the only data available for this purpose. Therefore, results do not include energy efficiency improvements resulting from technological improvements in vehicles or fuels, but they include energy efficiency improvements resulting from suitable choices of vehicle type and a better logistics and, of course, those resulting from improvements in infrastructures and driving. Moreover, in relation to the trend change in the progression of energy intensity in 2004, according to the database used, the EPTMC, there is a greater use in road freight activity of higher power vehicles since 2004. Along with the activity increase, the share in fuel consumption of articulated vehicles of a gross vehicle weight superior to 40 tonnes was 0% until 2004 and 2% thereafter. As a result, there was a significant increase in energy intensity, which would explain the trend change in energy intensity in 2004. Lastly, the trend change in energy intensity in 2009 may be linked to the decline in the fuel prices, which dropped by 20.1% in 2009 with respect to 2008.

Future research should focus on studying in greater detail different factors related to logistics that have influenced the progression of the real energy intensity index, and thus find mechanisms that could lead to improvements, specially through designing policies aimed to commodity groups that have revealed a bad behaviour. If an energy intensive commodity group such as “Transport equipment, machinery, …” has managed to achieve greater energy efficiency in its transport, it is conceivable that this could also be achieved in the transport of other commodity groups. Nevertheless, policies should be systematically adjusted to take into account possible significant changes in this behaviour over time. Similarly, the analysis should be extended by including another important mode of freight transport, namely rail. The analysis could then be carried out by disaggregating by commodity group and by mode of transport. To make possible this analysis, official data should provide information on tonnes-kilometre by commodity group carried by rail (classified as in EPTMC) and related energy consumption, which is not yet available. Thus, once we know more precisely which are the improvements of energy intensity in freight transport that could be achieved through a larger participation of rail at the expense of road, policy makers could then design measures aimed to improve energy intensity. For example, by increasing specially the share of rail in freight transport in the commodity groups which are more energy intensive in its transport by road. Finally, this later research could also be extended to study the trend in the intensity of greenhouse gas emissions of freight transport and its drivers. The identification of the role played by structural and real emission intensity effects, and the examination of the magnitude of the changes observed by commodity group and its causes (changes in transport modes, use of fuels, and the extension of good practices, among other aspects), will orientate the design of the appropriate policies to help the mitigation of emissions in the sector.

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REFERENCES

Ang B.W. (1994) Decomposition of industrial energy consumption. The energy intensity approach. *Energy Economics*, vol.16, n.3, pp. 163–174.

Ang, B.W. (2004) Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy,* vol. 32, pp. 1131–1139.

Ang, B.W., Zhang, F. Q. (2000) A survey of index decomposition analysis in energy and environmental studies. *Energy*, vol. 25, pp.1149–1176.

Ang, B.W., Na Liu (2007) Handling zero values in the logarithmic mean Divisia index decomposition approach. *Energy Policy*, vol. 35, pp.238–426.

Choi, K.H., Ang, B.W. (2012) Attribution of changes in Divisia real energy intensity index – An extension to index decomposition analysis. *Energy Economics*, vol. 34, pp.171–176.

Ehlrich P., Holdren J. (1971) Impact of population growth. Science, vol. 171, pp. 1212–1217.

Ehrlich P., Holdren J. (1972) A bulletin dialogue on the 'Closing Circle'. Critique: One dimensional ecology. Bulletin of the Atomic Scientists, vol 28(5), pp. 16–27.

European Commision. *Eurostat* (2014) Luxemburg: Office for Official Publications of the European Communities. Retrieved: June 25, 2014 < http://epp.eurostat.ec.europa.eu >

International Energy Agency (IEA) (2013) Energy Policy Highlights. OECD/IEA, Paris.

International Energy Agency (IEA) (2014) Energy Efficiency Indicators: Fundamentals on Statistics. OECD/IEA, Paris.

Instituto Nacional de Estadística (INE) (2014) Madrid: INE. Retrieved: September 12, 2014 < http://www.ine.es/ >

Instituto para la Diversificación y Ahorro de la Energía (IDAE) (2006) *Guía Para la Gestión del Combustible en las Flotas de Transporte por Carretera*. Ministerio de Industria, Turismo y Comercio, MadridInstituto para la Diversificación y Ahorro de la Energía (IDAE) (2010a) *Informe Anual de Indicadores Energéticos*. Año 2009. Ministerio de Industria, Turismo y Comercio, Madrid.

Instituto para la Diversificación y Ahorro de la Energía (IDAE) (2010b) *Factores de Conversión Energía Final, Energía Primaria y Factores de Emisión de CO_2*. Ministerio de Industria, Turismo y Comercio, Madrid.

Kamakaté, F., Schipper (2009) Trends in truck freight energy use and carbon emissions in selected OECD countries from 1973 to 2005. *Energy Policy*, vol. 37, pp. 3743-3751.

Lenzen, M. (2006) Decomposition analysis and the mean-rate-of-change index. *Applied Energy*, vol. 83, pp. 185-198.

Mendiluce, M., Schipper L., (2011) Trends in passenger transport and freight energy use in Spain. *Energy Policy,* vol. 39, pp.6466-6475.

Ministerio de Fomento (2001) Plan estratégico para el sector del transporte de mercancías por carretera PETRA. Dirección General de Transporte Terrestre. Ministerio de Fomento, Madrid.

Ministerio de Fomento (2008) *Plan Estratégico de Actuación para el Transporte de Mercancías por Carretera PETRA II*. Dirección General de Transportes por Carretera. Ministerio de Fomento, Madrid.

Ministerio de Fomento (2010a) Observatorio del Mercado de transporte de mercancías por carretera, nº 19. Secretaría de Estado de Transportes. Dirección General de Transporte Terrestre. Ministerio de Fomento, Madrid.

Ministerio de Fomento (2010b) Plan Estratégico para el Impulso del Transporte Ferroviario de Mercancías en España. Ministerio de Fomento, Madrid.

Ministerio de Fomento (2013) Encuesta Permanente del Transporte de Mercancías por Carretera (EPTMC), 1996–2012. Subdirección General de Estadísticas Ministerio de Fomento. Ministerio de Fomento. Available at: http://www.fomento.es/

Pérez Martínez, P.J., Monzón de Cáceres, A. (2008) Consumo de energía por el transporte en España y tendencias de emisión. *Observatorio Medioambiental*, vol.11, pp. 127-147.

Pérez Martínez, P.J. (2009) The vehicle approach for freight road transport energy and environmental analysis in Spain. *European Transport Research Review*, vol.1, pp.75-85

Pérez Martínez, P.J. (2010) Freight transport, Energy Use, and Emission Trends in Spain. *Transportation Research Record: Journal of the Transportation Research Board*, vol. 2191, pp.16-22.

Sorrell, S., Lehtonen, M., Stapleton, L., Pujol, J., Champion, T. (2009) Decomposing road freight energy use in the United Kingdom, *Energy Policy*, vol. 37, pp. 3115–3129

Sorrell, S., Lehtonen, M., Stapleton, L., Pujol, J., Champion, T. (2012) Decoupling of road freight energy use from economic growth in the United Kingdom , *Energy Policy*, vol. 41, pp.84-97.

Stead D. (2001) Transport intensity in Europe – indicators and trends. *Transport Policy*, vol.8, issue 1, pp. 29-46.

Sun, J.W., Ang, B.W. (2000) Some properties of an exact energy decomposition model. *Energy*, vol. 25, issue 12, pp. 1177-1188.

Vanek, F.M., Campbell, J.B. (1999) UK road freight energy use by product: trends and analysis from 1985 to 1995. *Transport Policy*, vol. 6, pp.237-246

Vanek, F.M., Morlok, E.K. (2000) Improving the energy efficiency of freight in the United States through commodity-based analysis: justification and implementation. *Transportation Research Part D*, vol. 5, pp. 11-29.

APPENDIX

[TABLES 7 – 11 ABOUT HERE]