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**ANÁLISIS DE LAS VARIABLES
EXPLICATIVAS DEL DESCOPLAMIENTO
DEL CRECIMIENTO ECONÓMICO Y DE LA
DEMANDA DE TRANSPORTE DE
MERCANCÍAS POR CARRETERA EN
EUROPA A TRAVÉS DE UN MODELO
INPUT-OUTPUT**

TESIS DOCTORAL

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**ANALYSIS OF THE KEY DRIVERS FOR ROAD
FREIGHT TRANSPORT DECOUPLING IN
EUROPE FROM AN INPUT-OUTPUT
APPROACH**

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EL PRESIENTE

LOS VOCALES

EL SECRETARIO

*A mi madre.
Tu recuerdo me da fuerzas
para luchar por alcanzar cada una
de mis metas.*

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ABSTRACT

Traditionally, there has been an historic correlation between transport growth and the economy. As a consequence of that trend, aggregate economic variables such as Gross Domestic Product (GDP) have been the mostly applied to explain freight transport demand and to develop forecasting analysis. However, last years revealed how freight transport has remained stable or even declined under economic growth scenarios in some countries.

These evidence have led to decoupling between road freight transport and the economic growth, which has been understood as an opportunity for boosting sustainable development by the reduction of the environmental impacts of road transport. With this aim in mind, among the proposal of other measures, one of the key challenges of the European Union has been the promotion of strategies aimed at promoting decoupling of road transport growth from economic development.

Based on the above considerations, the objective of this thesis is about providing knowledge for explaining road freight traffic demand over time in Europe. The research looks for the key drivers of decoupling in order to lay the foundations for the definition of the most appropriate decoupling strategies. This is particularly relevant for policymakers and transport practitioners.

The research involves analysis at the macro level of national road traffic though a methodology based on the application of Input-Output tables together with descriptive variables of the European transport systems and procedures. This also provides a cross-country comparison of several European Union countries in order to find the reason for the similarities and divergences of their past road freight traffic trends and decoupling levels.

RESUMEN

Tradicionalmente, la demanda de transporte de mercancías por carretera ha estado íntimamente ligada al crecimiento económico, lo que ha hecho que variables económicas agregadas como el PIB hayan sido ampliamente utilizadas para construir modelos de previsión de demanda de tráfico. Sin embargo, en los últimos años, algunas evidencias empíricas han demostrado cómo, en diversos países, el volumen de demanda de transporte se mantenía estable o disminuía incluso bajo escenarios de expansión económica.

Estas evidencias han originado que estas situaciones de desacoplamiento entre la economía y el transporte, concretamente entre el transporte de mercancías por carretera, hayan sido entendidas como una oportunidad de promover el desarrollo sostenible del transporte disminuyendo con ellas la gran cantidad de externalidades a las que da lugar el tráfico de camiones. Por ello, uno de los objetivos que ha fijado la Unión Europea ha sido el de reforzar estas tendencias mediante el desarrollo e implantación de diferentes estrategias y políticas de desacoplamiento.

En este contexto, esta tesis doctoral tiene como principal objetivo mejorar el conocimiento actual en la explicación de la evolución de la demanda de transporte de mercancías en Europa a lo largo del tiempo, y en concreto, identificar los principales factores y variables que son capaces de originar tendencias de desacoplamiento del transporte por carretera y el desarrollo económico. Esto puede ayudar a sentar las bases para definir las estrategias sostenibles de transporte más apropiadas en este ámbito.

La investigación realiza un análisis macroeconómico del tráfico por carretera a nivel nacional a través de una metodología que integra tablas Inputs-Output con variables descriptivas de los sistemas de transporte de cada país. Desarrolla a su vez un análisis comparativo de las tendencias seguidas en diferentes países de la Unión Europea y de los niveles de desacoplamiento alcanzados con el objetivo de dar las razones que han dado lugar a las semejanzas y diferencias encontradas en el pasado.

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ANALYSIS OF THE KEY DRIVERS FOR ROAD FREIGHT TRANSPORT DECOUPLING IN EUROPE FROM AN INPUT-OUTPUT APPROACH

1. INTRODUCTION

“Transport is vital for everyone, and with the right mix of solutions sustainable transport will help us to realize a better future by helping to reduce poverty while protecting the planet and driving economic growth.”

United Nations, Department of Economic and Social Affairs, 2014

Transport is essential for economic development, but it also causes a wide range of externalities. As a consequence of that, one of the main challenges for policy makers in Europe over the last few decades has been to reconcile economic growth with sustainable social and environmental transport conditions since in most industrialized countries there has been a strong positive relationship between economic and transport growth. Emissions of greenhouse gases from transportation, especially from road transport, are contributing to cause global warming which is likely to produce more natural disasters with negative consequences for the society. This trend has been stressed by the rise of transport congestion especially in urban areas.

Past trends indicated that for decades the European transport system has been moving away from sustainability. This fact resulted crucial to emphasize the need for actions aimed at reaching certain transport sustainability targets at both national and European levels. This challenge, taken up by the European Union (EU), has been seeking to increase transport efficiency through the full internalization of negative side-effects of transport (European Commission 2001a).

With this aim in mind, the EU has been promoting some policy measures to reduce the road freight transport-related externalities (European Commission 2003) by, for instance, transferring some freight traffic volumes from the road to more competitive and efficient modes. Such type of measures are necessary because, despite certain disparities among countries, there are still common features

regarding freight transport in Europe like the great modal share of the road compared to other modes.

Among the proposal of other measures, one of the key challenges for implementing this strategy has been the promotion of the decoupling of road transport growth from economic development in order to mitigate the environmental impacts of transport caused by economic growth (OECD 2006a).

The concept of decoupling has been widely treated in institutional documents. It was the focus of the Standing Advisory Committee on Trunk Road Assessment (SACTRA) report in the United Kingdom in 1999 and it was discussed in policy reports like the *White Paper European Transport Policy for 2020: Time to Decide* (European Commission 2001b), understanding it as an opportunity for boosting sustainable development. Moreover, there are a number of previous research works in this field focused on analysing the main causes of decoupling in different countries, and particularly in the European area.

This Introduction chapter intends to provide an overview of the State of knowledge and practice about road freight decoupling, focused mainly in Europe. It explains the methodological framework developed in this Doctoral Thesis in order to fill part of the scientific gaps found in this research area, particularly for the field of road freight transport. To that end, this is structured as follows: (i) review of the current transport trends and decoupling policies in Europe (Section 1.1), (ii) review of the previous findings about the link between transport and the economy and about decoupling issue (Section 1.2); (iii) detailed description of the Input-Output methodology that will be used in this Doctoral Thesis (Section 1.3); (iv) identification of the main objectives and research areas addressed in this thesis (Section 1.4).

1.1 State of play of European Union transport issues

1.1.1. An overview about the European Transport Policy

The management of transport market involves multiple issues like rail, road, waterways, and combined transport, environment, sustainability, social costs, international transport, infrastructure needs, people with reduced mobility, road safety, traffic management, road traffic information and new communications technologies.

Within this context, for a long time European transport policy has been focused on promoting higher degrees of efficiency in the flows of transport — for both freight and passengers— for successfully developing economies while reducing environmental threats and enhancing the social welfare.

Transport policies in the EU were assigned with a high priority through the Common Transport Policy defined in the Treaty of Rome (1957). This Treaty made clear that in transport, as in any other sector, the main concern should be to remove border charges, duties and discriminations between Member States. In that way, those measures would contribute to the free movement of individuals, enterprises and goods by the realization of a common market among Member States.

In 1992, the Treaty of Maastricht reinforced the political, institutional and budgetary foundations for transport policy, among other things. In addition, it included the concept of the trans-European network contributing to come up with a plan for the development of transport infrastructure at European level with the aid of Community funding.

In this same year, the first White Paper of the common transport policy was issued focusing on the opening-up of transport market along the lines traced in the 1985 White Paper “Completing the internal market”. It is worth noting that it was generally achieved except in the rail sector.

Later on, the White Paper: *European transport policy for 2010: time to decide* (European Commission 2001) proposed some 60 specific measures to be taken at Community Level that included an action programme with specific targets on issues like road safety, modal split and revitalization of railways (whose share – in terms of tonne-km – of the goods market fell from 21% to 8.4% between 1970 and 1998).

It is widely known that transport generates several non-negligible environmental impacts: greenhouse gases, noise, accidents, health damaging emissions (NO_x, SO_x, particulates, CO), and particularly road and air sectors are commonly understood as the most polluted sectors. As a consequence, one of the main goals of the 2001 White Paper was the promotion of decoupling transport growth from growth in GDP. This was also an objective of the Sustainable Development Strategy adopted in Gothenburg in June 2001, when the European Council pointed out:

“a sustainable policy should tackle ... the full internalization of social and environmental costs. Action is needed to bring about a significant decoupling of transport growth and GDP growth, in particular by a shift from road to rail, water and public passenger transport”.

Previous research studies in decoupling state has shown that the levels of decoupling are quite differentiated by country, as countries such as Portugal, Spain, Greece, Bulgaria, Ireland, Estonia, Romania and Austria showed low or zero levels during the past years, whereas Slovakia, Cyprus, Denmark, Finland, Belgium and the U.K already started to show clear decoupling trends (Ponti et al. 2013).

The White Paper: *Keep Europe moving: a transport policy for sustainable mobility* (European Commission 2006) outlines the guidelines of the European Commission for the future transport policy. Together with some of the actions foreseen in the 2001 White Paper, it referred to additional instruments needed to achieve this purpose like a freight logistics action plan and an intelligent transport systems to make mobility greener and more efficient.

Finally, one of the most recent documents in EU transport policy is the White paper: *Roadmap to a Single European Transport Area. Towards a Competitive and Resource Efficient Transport System* (European Commission 2011). This paper supported

some items like the removal of major barriers in transport systems or the cutting of carbon emissions in transport by 60% by 2050. It also highlighted the necessity of developing new fuel and propulsion systems, the better use of information systems, market based incentives (like “user pays” and “polluter pays” principles) together with —once again— a modal shift from road to more friendly-environment modes.

As seen, the EU Transport Policy has provided common guidelines to the Member States in order to achieve a common efficient and sustainable transport system. However, it is worth noting that each member has considerable flexibility to implement these policies, it is the same with policies promoting the decoupling issue in road freight transport, so that may lead to different transport patterns in each one of them.

1.1.2. Current freight transport trends in the EU

The evolution of the freight transport market in Europe has shown different trends during last decades, partly due to some of the treaties or guidelines mentioned in previous section.

Following years of almost continuous growth from 2003 to 2007, the volume of tonne-kms relative to GDP declined sharply in the European Union due to the arrival of the economic crisis. As seen in Figure 1.1, it was not until 2010 when a new increase could be observed.

Source: Own elaboration using data from Eurostat

Figure 1.1. Evolution of transport (tonne-kms) relative to GDP in the European Union (27 countries)

This trend is similar to the one followed by road freight transport that accounted for a decrease of 10% between 2008 and 2009 in the EU-27 and 11% in EU-15. In fact, the only two Member States which recorded growth in time of crisis were Poland (nearly +10%) and Bulgaria, which recorded an increase of +16% (Wrzesinska 2011).

During this period, it is important to note the notable rise in cabotage (see Figure 1.2). This was the result of a significant growth in the cabotage performed by Bulgarian hauliers, as well as the growth of Latvia and Poland. These countries have become in some of the biggest caboteurs in the EU, followed by Luxembourg, Netherlands and Germany. Thus, this suggests that the new Member States have been capable of maintaining, and even strengthening, their position on the road freight market despite the global economic downturn.

Source: Eurostat statistics

Figure 1.2. Evolution of EU-27 road freight transport (tonne-kms) between 2004 and 2009. Index 2004=100

As Figure 1.3 shows, road transport, which is the most energy and carbon intensive land transportation mode, has become the dominant mode within the European Union, accounting for a the highest share of inland freight transport (nearly 80%) compared to other modes.

Source: Own elaboration based on Eurostat data

Figure 1.3. Modal split (in tonnes) for inland freight transport in EU-27 between 2000 and 2012

However, the comparison of several countries shows some differences in the modal split (Figure 1.4):

- In some European countries road share is considerably higher than the rest of modes. This situation appears in cases like Cyprus, the UK, Ireland or Spain.
- Rail transport has a very high share in Lithuania, Latvia and Estonia and a relatively high share in other countries such as Sweden, Belgium or Germany.
- Inland navigation is very high in the Netherlands and Bulgaria but, in contrast, there is no inland navigation in countries like Sweden or Denmark.

Source: Eurostat

Figure 1.4. Modal split (in tonnes) for inland freight transport in 2009 by EU countries

On the other hand, looking at the importance of the different types of goods moved by road in the EU, statistic figures show the wide differences between them depending on whether transport is measured in tonnes or tonne-kilometres. Heavy products like raw materials (sand, gravel, ores and cement) and building materials are normally transported over short distances, so they have prominence when transport is measured in tonnes. By contrast, in tonne-kms (combining tonnage of goods with distances) food products, beverages and tobacco are the most important groups —these products are manufactured in a limited number of production centres and then dispatched over long distances—.

It is worth noting that transport movements in all distance classes suffered a significant downturn when the economic crisis arrived (see Figure 1.5), with longer distance journeys dropping by 16% below the 2006 level in 2009. Shorter distance transport also fell by 9% compared to its 2006 level, while middle distance transport only showed a 6% decrease in tonne-kms.

In 2010, longer and middle distance transport recovered, while on the contrary short distance transport experienced another small decline compared to 2009. This

might be caused partly due to the continuing weakness of the European construction sector since 2007 which, as said before, is a major driver for this type of transport.

Source: Eurostat

Figure 1.5. Evolution of total transport by distance classes in EU-27. (Index 2006=100, based on tonne-kms)

Finally, there are some aspects worth mentioning about the trends that EU Member States have followed in the use of transport resources. Regarding to the types of vehicles moved in the EU for freight transport, it is observed that the average vehicle loads rose significantly in 2007, and began a sharp decline in 2008 (see Figure 1.6). This may be caused by, on the one hand, the general fall in construction activity in Europe, and on the other hand, the faster decrease of international transport compared to national transport in this period in some European countries—overall, international transport has traditionally shown higher loads than national transport.

Moreover, there are significant differences between countries as higher loads has been recorded by countries with heavy products —e.g. timber for Sweden or fruits and vegetables for Spain.

UK: 2009 data

Source: Eurostat

Figure 1.6. Average vehicle loads for total road transport in EU-27 (tonnes)

Furthermore, the proportion of empty vehicle-kilometres in total veh-kms and its evolution over time is an important measure of the efficiency of road freight transport. In this respect, it is highlighted that for the majority of countries the rate of empty running for national transport has doubled the value for international transport, and that during the last years this ratio seemed to be a little lower than in the past — 24% in 2010 while 25% in 2007.

1.1.3. Main trends in European freight transport logistics

As the demand for freight transportation services is a derived demand from production, this is strongly influenced by the organization and management of supply chains. Therefore, it is a fact that transport system evolves and adapts progressively in order to respond to the requirements imposed by the emerging new organization of logistics systems. As Woxenius and Sjöstedt (2003) argued (and it is shown in Figure 1.7), logistics and transport systems are complementary.

Source: Woxenius and Sjöstedt (2003)

Figure 1.7. Complementarity between transport and logistics systems.

In recent years numerous industries have made considerable efforts to improve their logistical performance by optimizing the fleets, managing their routes, and designing logistics centres.

TRILOG-Europe project (European Commission 1999) lined out the trends initiated during 80s and 90s, which are displayed in Table 1.1. They have been driven by the combination of factors such as trade liberalisation, increase in the value of trade, trade specialisation and technology advances.

Table 1.1. Taxonomy of logistics and supply chain trends

Level of logistical decision making	Trend
Restructuring of logistics systems	Spatial concentration of production and inventory Development of break-bulk / transshipment systems Creation of hub-satellite networks
Realignment of supply chain	Concentration of international trade on hub ports Rationalisation of the supply base Vertical disintegration of production Wider geographical sourcing of supplies Wider distribution of finished products Postponement / local customisation Increased direct delivery
Rescheduling of product flows	Time-compression principles applied in retail and manufacturing Increase in retailers' control over supply chain Growth of 'nominated day' deliveries and timed delivery systems
Management of distribution	Changes in freight modal split Reduction in international transport costs Impact of legislation and regulation Increased use of information and communications technology Developments in vehicle and handling technology
Changes in product design	Complexity, Packaging, Modularity Globalisation, growth of E-commerce and dematerialisation of freight

Source: TRILOG-Europe project (1999)

In the last decades, a clear trend emerged aimed at concentrating production and inventory in fewer locations as a result of both a reduction in the total number of factories and greater plant specialization, based on the intensive use of economies of scale. This led to more transport-intensive logistical systems (in tonne-kms) as reducing the number of stockholding points contributed to increase the average length of haul between production and distribution centres, and between distribution centres and final consumers. This was evidenced by Kveiborg and

Fosgerau (2007), who reported increasing average haulage lengths in the 1970s, 1980s and 1990s in many European countries. Nevertheless, it has been claimed that this effect is likely to have been less notable during recent years because of both the slow-down in network reconfiguration and the outsourcing of delivery processes to large companies still managing many warehouses (Crespo et al. 2006).

Furthermore, the moving to just-in-time (JIT) and quick response (QR) distribution techniques reduced the average size of deliveries. As a consequence of that, hub-satellite networks were promoted rather than conventional systems with numerous warehouses. In this type of configuration, the hub is the focus of the system from where radial routes depart to the different geographical areas covered by the supply chain. It is worth noting that these systems may result in adding additional nodes to the supply chain increasing final tonne-kms. However, the concentration of truck flows in a determined number of routes may lead to higher load factors and vehicle size, and therefore to decreasing veh-kms.

On the other hand, the increase of direct deliveries was possible thanks to the improvements in information and communication technologies (ICT), and particularly through electronic media. E-commerce has played a key role as a factor affecting new logistics systems, being supported with the centralisation of inventory mentioned above. At the same time, the electronic distribution of products like downloadable music or books is now contributing to dematerialisation and transport reductions.

Finally, it is worthy to mention, among the rest of things reflected in Table 1.1, that the economies of scale in terminal and vehicle operation have led to the concentration of international trade in a smaller number of hub ports and airports in Europe. The new increasing size transoceanic vessels can only operate in the largest ports such as Rotterdam, defining both the structure of international supply chains and routes of international transport in Europe.

1.2 Links between transport and the economy

It is widely accepted by the literature that there exist direct links between transport and the economy, and as a consequence of that belief, aggregate economic variables such as Gross Domestic Product (GDP) have been traditionally used to explain freight transport demand.

The existing methodologies applied to understand road freight transport trends look for simulating the behaviour of the multiple factors influencing transport by using mathematical models (e.g. Jong, Gunn. and Walker, 2004 and Tavasszy, 2006). However, previous studies highlight the complexity of developing such type of models, partly because of the numerous factors involved in shipping the commodities in each country, and partly because of that lack of available data (Elaurant and Bates, 2007).

As said before, GDP has been generally applied for forecasting transport growth, and particularly road freight transport demand. This is because there has been a historical high correlation between economic development and road transport demand (Standing Advisory Committee on Trunk Road Assessment-SACTRA, 1999). Several econometric models have proven a close correlation between tonne-kms and GDP growth in many countries (e.g.: Bennathan et al., 1992). This issue, also known as coupling, has drawn a lot of attention in the literature as some countries have gradually shown evidence of breaking this correlation during the last decades (Banister and Stead, 2002 and Gilbert and Nadeau, 2002).

According to Costa (1988), transport demand, particularly freight transport, is a derived demand from economic activity and the restructuring of the economy may lead to changes in the goods produced and moved, and therefore, in transport requirements. Specifically, freight activity is driven by complex and interlinked production processes and trade relationships, so analysing the freight transport in terms of both supply and demand may allow to define more realistic truck flows (Holguín-Veras and Thorson 2007).

On the other hand, as described in the previous section, recent years have seen increasing specialization, new production organization systems such as ‘just-in-time’ distribution, and an ever greater concentration of manufacturing and storage (McKinnon and Woodburn, 1996). All these factors lead to changes in transport patterns, as supply chain organization influences aspects such as transport distances or modal split (OECD, 2006).

1.2.1. Coupling vs. Decoupling at global level. Empirical evidence

In most industrialized countries freight transport accounts for a significant share of GDP (Crainic and Laporte, 1997), therefore GDP has been the most used variable to explain freight transport trends. Indeed, the correlation between tonne-kms and GDP—that is the coupling level—is used to simulate prognosis scenarios for transport demand. However, several authors, such as McKinnon and Woodburn (1996) and Kveiborg and Fosgerau (2007), criticize this approach claiming that industrial production levels of a country define better real transport demand rather than GDP.

In some countries, transport has continuously grown, but at a lower rate than GDP, in a process that can be defined as weak decoupling—that is, the link between transport and the economy has been weakened. In other countries, transport growth has been negative while economic growth has been positive, which could be defined as strong or absolute decoupling—the link has been broken—(Ballingall et al., 2003). Numerous works have focused on these trends pointing out that decoupling levels were more likely to appear in ‘peripheral’ EU countries (e.g. Tapio, 2005 and McKinnon, 2007) due to the increasing freight transport in centrally located countries.

Other recent studies (e.g. Banister and Stead, 2002; Gilbert y Nadeau, 2002; OECD, 2003) have analysed historical evidence for decoupling and its likely potential impact in the future. One of the most important contributions to this field has been the European programme “RElationship between DEmand for Freight-transport and INdustrial Effects”—REDEFINE (NEI, 1997). This project examined road freight

transport trends in five European countries – France, Germany, the Netherlands, Sweden and the United Kingdom— between 1985 and 1995 concluding that rather than a decoupling, there had been a ‘recoupling’ of the growth of road freight transport and GDP in all but one of the case study countries (Sweden) and that these trends were likely to continue.

Some studies carried out in Japan or United States (OECD, 2003) or United Kingdom (McKinnon, 2007) showed clear decoupling trends. Banister and Stead (2002) pointed out that tonne-kms had been growing less than GDP since 1960 in US. In the UK, GDP grew by 21% between 1997 and 2005 while tonne-kms grew by only 8% in the same period (see Figure 1.8). Gilbert and Nadeau (2002) claimed that the concept of decoupling is perhaps of more concern in Europe than in North America.

Source: McKinnon (2007)

Figure 1.8. Real GDP, tonne-kms and tonne-kms by road trends in the United Kingdom, 1990-2004 (*index 1990=100*)

A cross-sectional study of a sample of 33 countries at different stages of development undertaken by The World Bank using 1989 data demonstrated that, although the relationship between GDP and road tonne-km was extremely close (Bennathan et al., 1992), notable divergences in tonne-kms/GDP elasticity were found. For the sample of 17 developed countries (including the UK) “the partial elasticity of tonne-kms by road with respect to GDP was about 1.02, while for the

rest of the sample it was about 1.28. Therefore, this research concluded that the level of development is a key factor when defining the existing link between road transport and the economy in a country.

Moreover, Schroten and Delft (2011) argued that some important aspects explaining the differences in decoupling levels between countries or continents are the geography, the urban planning schemes, the lack of alternatives to road transport, the supply of road transport infrastructure, the fuel prices and the transport taxes.

The research work of Tapio (2005) cited a weak relative decoupling between freight traffic (and also for passengers) and GDP during the 1990s in five countries: Finland, Sweden, the UK, Ireland and Luxembourg. By contrast, in the Netherlands and Portugal, he identified an expansive negative decoupling while transport volumes grew at higher rates than this GDP. In all the other countries of the EU-15, GDP decreased during that decade while transport continued to grow. Tapio emphasized the exceptionally high elasticity values observed in Germany in that period. According to Leonardi (2006), some drivers of that trend were the globalisation and the opening of Eastern European markets. The transport growth in this country was absorbed by the road mode due to the low competitiveness of German freight rail.

As seen in this section, the past evidence of decoupling in some countries between road freight transport and GDP led to different studies, such as those mentioned above, which try to define one way of measuring the decoupling state or explain it. So, the first question that arises is:

Is there current evidence of decoupling? or, conversely, can new coupling trends can be found in different countries?

1.2.2. A measure of the level of decoupling: Road freight transport intensity

1.2.2.1. An essential index

Decoupling has been often studied by analysing changes in the “transport intensity” (TI) ratio since some authors, such as Banister and Stead (2002), pointed out the necessity of considering it as a measure of the “transport efficiency”.

According to Baum (2000), this may be defined, for each economic sector or industry, as a ratio that measures road transport in tonne-kilometres per unit of GDP, as is expressed in the following equation (eq. 1.1).

$$TI_i = \frac{TK_i}{GDP_i} \quad (\text{eq. 1.1})$$

being TI_i the transport intensity of the economic sector i in a country, TK_i the tonne-kms for the commodities produced by sector i in this country, and GDP_i the Gross Domestic Product of that sector. It is noted that the volume of tonne-kms includes both the movement of national commodities and imported and exported goods.

The imports/exports of goods lead to an increase of transport demand, as those goods are carried along the entire supply chain network of a country from or to its borders or ports. Thus, the more accurate measure of tonne-kms for this analysis from a supply-side point of view should include commodities from national production processes together with imported goods —required all of them for intermediate industrial demand, household and government consumption and exports— (Voigtlaender, 2002).

For those cases focusing on road freight transport demand, Brunel (2005) defines “the road freight transport intensity” ratio (RFTI) as seen in (eq. 1.2), where $roadTK_i$ is the number of tonne-kms made by road freight vehicles in a country.

$$RFTI_i = \frac{roadTK_i}{GDP_i} \quad (\text{eq. 1.2})$$

Within this context, it is worth referring to different European projects that emphasize the importance of such index for analysing the link between transport and the economy. The European Union (EU) launched a strategy aimed at promoting decoupling between GDP growth and road transport demand, especially road freight transport demand, in order to reduce the negative side effects of this mode (European Commission, 2003). RFTI was then analysed to measure the decoupling level of each country.

The SACTRA report (1999) showed that road freight intensities may vary across countries. This was confirmed by Stead in 2001 after conducting a research that found out different RFTI values between 1975 and 1990 among European countries. So, he concluded that convergence of that indicator is quite unlikely in view of a number of national divergences such as economic structure, geography or land uses.

Although as seen, RFTI defined as the volume of transport related to GDP has been widely applied to analyse road freight transport demand, some authors have criticized this practice. Particularly, Banister and Stead (2002) held that although GDP provides a way of comparing economic activity in different countries, this measure has a number of limitations for explaining issues of economic restructuring. In response to this, authors such as Åhman (2004) argued that constructing sectional freight intensities based on sectors' production—that is sectorial output—is relevant for a deeper and more accurate understanding of transport growth in an economy rather than constructing these indexes based on GDP.

This approach that uses production instead of GDP has been already applied for analysing some goods and services of the economy such as energy or water consumption (see Cosmo et al. 2012 and Alcántara and Padilla 2003). Thus, on the basis of these examples, sectorial RFTI may be used to define global road freight transport intensity of a country as shown in (eq. 1.3.).

$$\frac{roadTK_C}{Output_C} = \sum_{i=1}^n \left(\frac{roadTK_i}{Output_{i,C}} \times \frac{Output_{i,C}}{Output_C} \right) \quad (\text{eq. 1.3})$$

being $roadTK_C$ the total tonne-kms moved in a country C; $Output_C$ the overall production in this country; $\frac{roadTK_i}{Output_{i,C}}$ the road freight transport intensity of the sector i; and finally, $\frac{Output_{i,C}}{Output_C}$ is the share of the goods produced by sector i in the total country's production.

According to Mckinnon (2007), some sectors, such as agriculture or mining, have higher transport intensities than service sectors. That is to say, they demand more tonne-kms by unit of their output. So, as services have expanded their share of total GDP, this has led to higher economic growth than in the transport sector (Åhman, 2004).

So, one question is stabilised:

How important are the economic structure and the restructuring processes of economies in a country for the promotion of decoupling?

On the other hand, sectorial RFTI values can vary across countries and evolve over time. Such differences are due to the specific characteristics and changes of each industry or the particular features of each country in the way of moving goods.

Therefore, other questions arise:

Do sectorial road freight transport intensities partly determine the final decoupling level in a country? How important is the evolution of these ratios over time in road freight transport behaviour?

1.2.2.2. Key variables driving road freight transport intensities

When looking at the literature, different studies defining the factors driving RFTI values and their evolution across both sectors and countries are found. Nevertheless, one of the most representative works in this field has been developed

by MacKinnon, together with other authors. This research is included in different reports and papers such as McKinnon and Woodburn 1996, McKinnon 2007, Piecyk and McKinnon 2009 or Piecyk and McKinnon 2010. McKinnon identified a number of ratios, closely related to logistics, which determine RFTI. Through them, it is possible to outline the amount of transport generated by a specified amount of production of a certain economic branch.

In case the volume of transport was measured in tonne-kms, these ratios are: the value density, the handling factor, the modal split and the average length of haul.

(1) The value density

This ratio defines the monetary value of a type of goods to their weight —i.e. $Output_i (\$)/tonnes_{produced,i}$ —.

Different categories of goods have widely different value densities —crude materials have lower value densities than manufactured products—. In addition, the value density may change over time because of the emergence of new technology in production processes that may lead to increases in variety and sophistication of products —that pushes up the price of the final goods—. Miniaturization and material substitution —by more durable and lighter materials— also contribute to increase value densities. Meanwhile, this ratio may be declined as a consequence of improved productivity, market liberalization, economies of scale and access to cheaper raw materials, as these factors may lead to lower prices of final products (McKinnon 2007).

(2) Handling factor

The handling factor ratio is the number of tonnes lifted per tonne produced — i.e. $tonnes_{lifted,i}/tonnes_{produced,i}$.

The handling requirements of goods include aspects of safety, packaging, consignment size, speed and punctuality (Steen 1998).

This ratio refers to the number of times a product is lifted between the origin and destination of the supply chain —from its production centre to the point where the good is finally consumed or used to make other manufactured

product— for each type of commodity. Hence changes in the handling factor of individual goods over time are substantially influenced by logistical changes and supply chain restructuring. It is noted that the handling factor may be considered as a proxy of the number of links in a supply chain.

Complex supply chains and the need for a great flexibility in transport operations may increase the average handling factor of a country. Factors such as vertical disintegration of production, insertion of more production stages or increasing imports contribute to higher handling factors. On the contrary, developing urban-mixed areas and the reduction in warehousing, in case distribution companies chose to ship directly to customers, exert the opposite effect.

From these two ratios —value density and handling factor— an intermediate index can be defined. This is the freight intensity, which is expressed as $tonnes_{lifted,i}/Output_i$ (\$)

(3) Modal split

Focusing on road freight transport, modal split is defined as the ratio between tonnes lifted in a commodity group that are taken by road and the total tonnes lifted by all transport modes for that commodity group — $tonnes_{lifted,road,i}/tonnes_{lifted,i}$ —.

Differences between sectors are significant because some commodities require greater flexibility than others, thus making shift from road to other modes, such as rail, more difficult.

As long as customers demand more customized products, more flexible, timely and frequent carries will be necessary, hence road will be favoured. As well as more processed commodity groups within manufacturing output require more intermediate trips that are usually made by road. Instead, locating production and warehouses close to ports and railway terminals promotes the construction of intermodal freight terminals bringing competitive benefits for alternative

modes of transport. Increasing road charges also contribute to change the modal split towards more sustainable transport modes.

(4) Length of haul

The average length of haul (in kms) is the ratio between tonne-kms and tonnes lifted by road for a given commodity group. It depends on the location of the different nodes of the supply chain as well as on road networks connections and their routes.

Factors like spatial concentration of production and inventory and internationalization push the average length of haul up. Increasing system services and higher network densities reduce it.

On the whole, the main groups transported over longer distances are food, agricultural products, chemicals basic metals and wood products. By contrast, products such as construction material are associated to short-distance haulages.

Thus, on the basis of these ratios, RFTI, measured in $\text{tonne} - \text{kms}_{\text{road},i} / \text{Output} (\$)$, is defined trough the following equation:

$$\begin{aligned} RFTI_i &= \frac{\text{tonne} - \text{kms}_{\text{road},i}}{\text{Output} (\$)} = \\ &= \underbrace{\frac{\text{tonnes}_{\text{produced},i}}{\text{Output}_i (\$)}}_{\text{inverse value density}} \times \underbrace{\frac{\text{tonnes}_{\text{lifted},i}}{\text{tonnes}_{\text{produced},i}}}_{\text{handling factor}} \times \underbrace{\frac{\text{tonnes}_{\text{lifted},\text{road},i}}{\text{tonnes}_{\text{lifted},i}}}_{\text{modal share}} \times \underbrace{\frac{\text{tonne} - \text{kms}_{\text{road},i}}{\text{tonnes}_{\text{lifted},\text{road},i}}}_{\text{average lenght of haul}} \quad (\text{eq.1.4}) \\ &= \underbrace{\frac{\text{tonnes}_{\text{lifted},i}}{\text{Output}_i (\$)}}_{\text{freight intensity}} \times \underbrace{\frac{\text{tonnes}_{\text{lifted},\text{road},i}}{\text{tonnes}_{\text{lifted},i}}}_{\text{modal share}} \times \underbrace{\frac{\text{tonne} - \text{kms}_{\text{road},i}}{\text{tonnes}_{\text{lifted},\text{road},i}}}_{\text{average lenght of haul}} \end{aligned}$$

On the other hand, although the most usual way to express RFTI measures the relation between tonne-kms and production, this also is found in other units such as $\text{veh} - \text{kms}_{\text{road},i} / \text{Output} (\$)$. In this case, in addition to the aforementioned ratios,

RFTI depends on two extra indices related to the organization and management of transport resources.

(5) Load factor

This ratio defines the relation between the total tonnes carried and the loaded vehicles $tonne_{road,i}/veh_{loaded,i}$, that could also be expressed as $tonne - kms_{road,i}/veh - kms_{loaded,i}$.

The loading factor depends on both the mix of vehicles (with different sizes and capacities) and on the lading factor of individual vehicles, that is the ratio of actual goods moved to the maximum tonne-kms achievable if the vehicles were loaded to their maximum carrying capacity.

Spatial concentration of production and inventory may lead to higher lading factors, and thereby higher loading factor. Using larger vehicles also contribute to increase the tonnes carried with the same traffic. On the contrary, the supply of customized products may lead to lower lading factors contributing to lower the loading efficiency of road freight transport. Changes in handling systems and packaging of some products can also affect this ratio and RFTI values.

(6) Empty running

The empty running ratio is the percentage of total vehicle-kilometres which run empty. This is the ratio between total vehicle-kilometres and loaded vehicle-kilometres— $veh - km_i/veh - kms_{loaded,i}$. Reduction of empty running results from reasons as the improvement of load factors, that is, greater use of systems services, concentration and network design rationalization.

So, for defining RFTI in $veh - kms_{road,i}/Output$ (\$) for an economic branch, it should be considered the inverse of the load factor and the empty running value (as seen in eq. 1.5).

$$RFTI_i = \frac{veh - km_i}{Output_i (\$)} = \underbrace{\frac{ton - km_{road,i}}{Output_i (\$)}}_{RFTI_{tonne-km/\$}} \times \underbrace{\frac{veh - km_{loaded,i}}{ton - km_{road,i}}}_{inverse\ load\ factor} \times \underbrace{\frac{veh - km_i}{veh - km_{loaded,i}}}_{empty\ running} \quad (eq.1.5)$$

1.2.2.3. Factors leading to new road freight transport intensities

Figure 1.9 shows the framework that connects the economic and freight transport measures with the structural and logistics parameters described in section 1.2.2.2.

As already pointed out, all of these variables are influenced by a wide range of logistics-related decisions and trends, product characteristics and external factors (Piecyk and McKinnon 2010).

Six sets of factors have a complex inter-relationship with the key freight transport variables (Piecyk and McKinnon 2010) as each set of factors exerts an influence on the key ratios driving sectorial road freight transport intensities:

- Product-related factors affect the nature of the transport operation and the transport requirements. For instance, perishable products must be sold and consumed immediately after production, so, normally, direct or short channel—that means the producer sells a product directly to a consumer without the help of intermediaries—is advisable. By contrast, for durable products, indirect or multilevel channel are common—the products are moved from the manufacturing business via distributors to wholesalers and then retail stores. In case of heavy and bulky products, direct or short channel is more suitable. Mostly, indivisible products are distributed directly to customers. Divisible products can be conveniently distributed by middlemen. Precious products, like gold, jewellery, certain chemicals, software, etc., are distributed using direct or short channels of distribution. In these cases, the use of direct and short channels can minimize the risk of theft or robbery.
- Structural factors determine the number, location and capacity of factories, production and distribution centres, warehouses and other facilities in the logistics system.

- Commercial factors are related to supply companies' sourcing and distribution strategies and policies that determine the way the distribution of goods is carried out.
- Operational factors affecting the scheduling of product flows.
- Functional factors are related to the management of transport resources — choice of the types of vehicle, planning of loads and routing of deliveries.
- External factors—such as government regulations and tax policies, macro-economic trends, market dynamics and advances/improvements in technology.

Source: Own elaboration based on Piecyk and McKinnon (2010)

Figure 1.9. Relationship between measures, key variables and determinants of road freight transport demand

ANALYSIS OF THE KEY DRIVERS FOR ROAD FREIGHT TRANSPORT DECOUPLING IN EUROPE FROM AN INPUT-OUTPUT APPROACH

The following table provides a synthetic presentation of some examples of factors —grouped into the six aforementioned categories— affecting the key ratios related to the organization of freight operations and road freight transport demand. This reviews how those factors could vary them.

Table 1.2. Factors affecting the key ratios driving road freight transport intensities

	Value density	Handling factor	Modal split	Length of haul	Load factor	Empty running
<i>Product-related factors</i>						
Increasing quality of goods	↑					
Miniaturization of products	↑					
Access to cheaper raw materials	↓	?(1)		?(1)		
Use of lighter materials	↑					
Adding more stages in the production chain	?	↑	↑			
Greater use of space-efficient packaging / handling equipment			↓		↑	
Design of products adapted to logistical requirements			↓			
<i>Structural factors</i>						
Spatial concentration of production and inventory		↓		↑	↑	
Development of urban consolidation centres		↓	↓	↓		
Relocation of production centres and warehouses			↓(↑)(2)	↓(↑)		
Load consolidation (hub-satellite networks, reduction of warehouses)		↓		↑	↑	
Concentration of international trade on hub ports		↓	↓	↑		
Vertical disintegration of production		↑	↑			
<i>Commercial factors</i>						
Improving productivity	↓		↓?		↑	
Increases in the volumes of goods and services traded online		↑	↑		↓	↑

	Value density	Handling factor	Modal split	Length of haul	Load factor	Empty running
<i>Operational factors</i>						
Application of JIT —Just In Time— principle		↑	↑		↓	↑
Increase in nominated day deliverables		↑	↑		↓	
<i>Functional factors</i>						
Increase in vehicle size and weight					↑	
Use of vehicle routing and scheduling systems						↓
Intermodality and shift away from road			↓			
<i>External factors</i>						
Fuel prices			↓			
Introduction of road charging			↓			
Investment in alternative transport modes/intermodality			↓			
Investment in telematics systems					↑	↓
Investment in new vehicle design					↑	

(1) Cheaper raw materials may be located faster/closer than traditional raw materials, and using them may involve more/less intermediate journeys as it may change production processes.

(2) Locating production and warehouses close to ports and railway terminals promotes the construction of intermodal freight terminals bringing competitive benefits for alternative modes of transport. Otherwise, road share would increase.

Source: Own elaboration partly based on Lehtonen (2008) and partly on Piecyk and McKinnon (2010)

1.2.2.4. Road freight transport intensity drivers for explaining decoupling

Several previous studies have analysed road transport trends and decoupling levels for a single country focusing on the micro-level. Their approach consisted of analysing the evolution of some of the key drivers of road freight transport intensity.

Within this context, the UK has been a targeted case study in this type of research works due to its pronounced decoupling trend. In the research by McKinnon (2007), the author listed different possible reasons for the trends observed in this country between 1997 and 2004. In addition to the reduction of the average length of haul, he noted that the increasing geographical coverage by domestic supply chains, the increase of road freight costs and the decline in road's share of the freight market were some of the most significant reasons promoting decoupling in this country during that period.

In this country Lehtonen (2006) identified clear decoupling trends during 1990s and provided a list of reasons for this situation by developing a decomposition analysis of road freight transport into different factors. He found that after this year the shortening of the average length of haul began to influence decoupling. During previous decades, the increase of the average haulage distances was identified as the main factor contributing to increase road transport (NEI, 1997), partly due to the concentration of the economic activity. However, the new trends pointed out by Lehtonen suggested that such long-established concentration of production and inventory was beginning to weaken.

In this respect, McKinnon (2007) pointed out that the average length of haul for road freight in the UK between 1998 and 2003 actually declined by an average of 0.1% per year, in contrast to the 2–2.5% annual increase over the previous twenty years. Particularly, this variable dropped by 5.2% in 2004.

Looking at other works analysing other countries like Finland, Liimatainen and Pöllänen (2013) pointed out that, in contrast to what happened in the UK, haulage distances tended to increase in this country while the growth of value density in all sectors appeared to be the main reason for the decreasing road freight transport intensity between 1995 and 2010. This trend is similar to the one found in Sweden between 1990 and 2008 by Eng-Larsson et al. (2012). The authors noted that this trend could be explained by the shift to a more knowledge-based manufacturing industry as well as a general transformation towards more service-oriented economies.

Liimatainen and Pöllänen (2013) also highlighted that, in Finland, modal split remained stable during their period of study since the road's share remained between 88.6% and 90.0%. According to this fact, they concluded that the modal split had virtually no effect on transport intensity, and therefore on road freight transport demand. By contrast, in the case of Sweden, Eng-Larsson et al. (2012) found that the experienced changes in modal split had contributed to increase road transport.

1.2.2.5. Importance of decoupling transport policies

As previously pointed out, the EU has backed a number of policy measures to reach transport sustainability at both the national and European levels. (European Commission 2003), and one of the key tools for accomplishing this goal is to promote the decoupling of road transport growth from economic development (OECD 2006a).

As Steen already mentioned in 1998: *“Decoupling strategies are not a single, easily understandable solution. They must consist of a multiplicity of individual measures which complement each other and which will take time to be implemented”*.

Then, the following research questions are the starting point for possible future decoupling recommendations:

Which are the main freight transport drivers that may contribute to increasing or decreasing decoupling levels? What is the current effect of these factors in European road freight transport levels?

According to McKinnon and Woodburn (1996) there are four factors, already referred to in the previous sections, which link the transport characteristics — transport volumes, transport distances and transport efficiency — to the economic system. Then, they can be considered as key factors on the basis of which

decoupling measures and strategies could be designed to decrease road freight transport demand:

- The material intensity of the economy.
- The spatial structure of production and consumption.
- The handling requirements of goods.
- The organisation of transport.

Three basic strategies, which may be put into operation through different basic policy approaches —lifestyle-oriented policies, market-oriented policies and regulation-oriented policies— allow the targeting of assistance to the specific needs of modifying one or several of these factors (Figure 1.10):

- Reduction of the spatial range of material flows.
- Optimization of transport organization.
- Dematerialization of the economy.

On the one hand, decoupling can be achieved by reducing RFTI that implies the two first strategies: reduction of the spatial range of material flows and optimization of transport organization. This is because this ratio involves different aspects such as the average distance of the trips —based on the geographical location of production and consumption poles—, the structure of the supply chain, management of the transport system, the evolution of the modal split and the use of transport resources (as explained in section 1.2.2.2). RFTI can be improved by both implementing logistical changes and fostering modal split. Another policy that may play a part in reducing RFTI is encouraging land-use planners to locate production and consumption hubs closer to each other. Transport distances and modes depend on the spatial organisation of the supply chains (OECD 2006a), so spatial policies may be a means of creating mixed-use areas that bring producers —and consumers— in the chain into closer proximity, thereby decreasing derived demand. The reduction in the spatial ranges of production networks produces fewer requirements for road transport and shorter haulage lengths.

Source: Own elaboration based on Steen (1998) and (OECD 2006b)
Figure 1.10. Strategies for decoupling freight transport from economic growth

Decoupling may also be encouraged through the organisation of transport chains, with a greater shift to more efficient modes such as rail or barge. Increased investment in intermodality would favour decoupling by transferring freight to cleaner modes while improving the efficiency of transport systems. Other measures that would make these alternatives more competitive across Europe include the harmonisation of rail regulation (OECD 2004). Finally, certain tax instruments such as emission charges or road tax reforms would have the likely effect of making other transport modes more attractive to shippers.

The way transport resources are used and transport systems are organized are key factors in defining the transport efficiency of a country. Furthermore, the investment in new vehicle design through bigger trucks allowed by governments, may contribute to increase decoupling.

On the other hand, dematerialization of the economies is found as other strategy for promoting decoupling. This is defined as the reduction of material resources needed per unit of GDP. It involves a shift away from economies based on the increasing consumption of raw materials. As said earlier, the shift from manufacture-oriented transport-intensive economies to service-oriented economies implies less transport demand to keep the same economic growth. Policy measures aimed at dematerializing the economy may have a reducing effect on road freight transport demand and enhance the efficiency of the remaining production processes by decreasing transport requirements (Schleicher-Tappeser, Hey and Steen 1998).

Dematerialization may be the result of both structural changes and technological innovations that can contribute to improving processes and product designs. The result may be the requirement of fewer amounts of certain inputs to produce articles of the same quality. Therefore policies involving investment in new techniques to upgrade manufacturing processes, and new materials —lighter and more durable—, will change both backward and forward sectorial linkages in production processes and may ultimately reduce freight transport needs.

1.3 Input-Output approach

1.3.1. Approaches for an economic analysis of transport

There are various techniques that can be used to evaluate different systems, programmes and policies from an economic point of view. Each one of them is focused on some specific targets for carrying out the economic analysis of transport sector, depending on whether it is considered: a macro, meso or a micro economic approach.

Macroeconomic methods aim at developing an overall analysis of the economic situation in a specific country or region. These instruments deal in particular with the evolution of aspects such as goods, services, assets or labour within an aggregate level of markets (Bolt et al. 2004).

Macroeconomic approaches are regularly either Keynesian or Neo-classic drawing the national accounting such as Gross Domestic Product (GDP), domestic consumption or domestic employment as a measure of welfare. Most of macroeconomic assessment approaches have been focused on overall impacts by estimating effects on productivity of public capital in general, and of transport infrastructure using production functions (see for more details in Aschauer et al. 1994). Although several criticisms to these macro approaches have been devised (see for instance Holtz-Eakin y Schwartz 1995) they have had a wide development, and moreover, other different tools have been developed using Vector Auto Regression (VAR) models or econometric approaches (Sturm, Jacobsy Groote 1999; Pereira y Andraz 2010).

On the other hand, within the context of transport systems, microeconomic tools are used to analyse specific aspects through the comparison of changes either in transport costs or transport time. There are various approaches that have been largely used such as Cost-Benefit-Analysis (CBA) —called sometimes Benefit-Cost Analysis (BCA)— Cost-Effectiveness Analysis (CEA), Multi- Criteria Analysis (MCA), Life-Cycle Cost Analysis (LCCA), and social and environmental impact methods,

among others. (Some examples can be seen in De Rus, 2011 or in Bekir Bartin, 2011).

The OECD (2002) acknowledges that microeconomic analysis is the most appropriate approach to define the optimal balance between profitability and investment in transport. By contrast, the macro level should be used to evaluate the long-term effects on the transport systems not covered by micro tools. It is worth noting that transport policy assessment procedures through traditional microeconomic and macroeconomic perspectives have been largely documented and well known. However, alternative assessment tools through the mesoeconomic framework are growing in order to evaluate effects not captured in those two conventional tools.

The mesoeconomic approach is considered as the intermediate level between macro and micro analysis (SEAGA 2003), in which the economic system is described considering the market relations and sectorial economic agents. Furthermore, this level of aggregation is flexible since it assists to move from macroeconomic to microeconomic level determining how macro level policies are translated into the micro level by disaggregating down markets according to characteristics, regions and time horizons.

The mesoeconomic approach has been accepted as a valuable tool for policy analysis. In this sense, these type of analysis is another useful way to approach the assessment of infrastructure and transport policies because this analysis allows a high degree of disaggregation and representation of the economy through Input-Output (IO) analysis, and Spatial Computable General Equilibrium (SCGE) analysis (see for instance Haimesy Jiang (2001) y Bröcker y Mercenier (2009)).

This research thesis has been developed focused on the evolution of road freight transport trends taking into account, among other issues, the economic situation of different European countries. Therefore, this aim could be initially analysed through a macroeconomic perspective by using the aforementioned IO model. Ten Raa (2005) held that this model partly has a macroeconomic character, but it also has a rigorous ground on micro techniques based on both production and consumption.

As a consequence the IO method has been sometimes defined as a mesoeconomic tool.

The IO methodology is based on the structural relationships of production over time and it allows measuring economic impacts on either a specific industry or macro level. This research has found that the level of disaggregation of the IO data provides a way to analyse road freight transport demand linking that with the economic structure of a country.

1.3.1.1. Using Input-Output Tables for transport

The necessity of knowing the influence of changes in the production structure and economic patterns that may influence transport demand over time led to a body of works in transport modelling. This is characterized by the development of transport IO models both at the urban and regional scale (see Ivanova (2014) for a deeper review).

The main reason for this trend is that several authors have pointed out the advantages of using these models in representing intersectorial interdependencies in production / consumption (Cascetta (2013)). This is crucial to define the interchange of goods —trade flows— and therefore the movement of goods in a region.

As previously said, research within this field has led to a number of operational land use-transportation models by incorporating spatial (or interregional) disaggregation data. Some examples are MEPLAN (Hunt and Echenique (1999)), TRANUS (de la Barra (1995)), PECAS (Hunt and Abraham (2003)) and RUBMIO (Kockelman et al (2005)). These models combine IO data with additional information for trade and travel choices (travel costs, location of activities and population, mode choice models, etc.). That means that they usually need a big amount of available additional micro data to describe travel flows.

The IO approach has also been used to conduct several analysis at the macro level for planning processes and policy design in sectors such as the energy sector (see

e.g. Lenzen and Foran (2001) and Alcántara and Padilla (2003)). It is noted that this type of studies has never been conducted for transportation field.

1.3.2. Source and basis of the Input-Output tables

The IO method consists on an economic model developed by Wassily Leontief in the 1930s. (Leontief 1936). This approach is aimed at analyzing the economic structure of a particular region or country by building a table that compiles economic data for a specific period of time —this is usually annual data. The fundamental information used concerns the monetary transactions between industries. These ones represent the flows of products from each sector (as producer/seller) to the rest of sectors of the economy (as a purchasers/buyers) (Pulido and Fontela 1993).

The term interindustry analysis is used within this context since the fundamental purpose of the IO framework is to analyse the interdependence of industries in an economy. The rows of such a table describe the distribution of a producer's output (Z) throughout the economy. The columns describe the composition of inputs required by a particular industry to produce its output. —That is to say, each cell z_{ij} shows the monetary value of the transaction from each sector i that acts as a producer, to each sector j , as consumer sectors—.These interindustry exchanges of goods constitute the blue portion of the table depicted in Figure 3.1.

The additional columns, labelled Final Demand (f), record the sales by each sector to final markets, such as personal consumption purchases and sales to the federal government. They also include the export volumes of each type of goods and services (E).

The additional rows are labelled Value Added (V) and Imports (I). Value Added accounts for the other (non-industrial) inputs to production, such as labour, depreciation of capital and indirect business taxes. As seen later, through this measures GDP can be calculated from an income approach.

		Sectors/Consumer industries							Final Demand (f)	TOTAL
		Sector 1	Sector 2	Sector 3	...	Sector j	...	Sector n		
Sectors/Productive industries	Sector 1	z_{11}	z_{12}	z_{13}		z_{1i}		z_{1n}	Personal Consumption Expenditures (PC) Governments Purchase of goods and services (PUC) Gross fixed capital formation (GFC) Exports (E)	Z
	Sector 2	z_{21}	z_{22}	z_{23}		z_{2i}		z_{2n}		
	Sector 3	z_{31}	z_{32}	z_{33}		z_{3i}		z_{3n}		
	...					$\vdots$		$\vdots$		
	Sector i	z_{i1}	z_{i2}	z_{i3}		z_{ij}		z_{in}		
	...							$\vdots$		
	Sector n	z_{n1}	z_{n2}	z_{n3}		z_{nj}		z_{nn}		
Value Added (v)		Employee compensation (W) Profit-type income and capital consumption allowance (P) Indirect business taxes (B)								
Imports		Imports (I)								
TOTAL		Z								

Interindustry exchanges (R)
 Total sectorial output
 Total sectorial input

Source: Own elaboration

Figure 1.11. Common Input-Output scheme

An IO table is built on the basis of statistic figures coming from government data bases, censuses and official surveys (Eurostat 2008) and shows:

- (1) The structure of the costs of production and income generated in the production processes of a specific geographic area (region, country, etc.).
- (2) The interindustry dependences.
- (3) The flow of goods and services produced within the national economy.
- (4) The flows of goods and services with the rest of the world.

Thus, an IO table can be regarded as an accounting system of a country, since interactions between market actors (productive and purchasing sectors representing industries) are characterized by an equilibrium between total supply —national production and imports—, and total demand — intermediate

consumption in the production processes, household and government consumption, investment and exports.

This rule is fulfilled not only for the overall economy, but for each one of the economic sectors. That is to say, the output Z_i from a producer sector i (eq. 1.6) is equal to the input Z_j (eq. 1.7) of the same sector acting as a consumer sector (it means if $i = j \rightarrow Z_i = Z_j$).

$$Z_i = \sum_{j=1}^n z_{ij} + f_i \quad (\text{eq. 1.6})$$

$$Z_j = \sum_{i=1}^n z_{ij} + v_j + I_j \quad (\text{eq. 1.7})$$

The IO tables provide a picture of each economy in a specific period of time. According to Schaffer (1999) four quadrants that give essential information can be identified. Quadrant I describes consumption patterns of households and other local final users of goods and services as private investors and governments. It also includes the export column, which shows sales to other industries and consumers outside the regional economy. Quadrant II draws the interindustry structure, showing production relationships and dependences in the economy, such as the ways raw materials and intermediate goods are used to produce final outputs for selling to other industries, to ultimate consumers and to exports. Quadrant III contains incomes of primary units of the economy, including the incomes of households, the depreciation and retained earnings of industries, and the taxes paid to the government. The quadrant also includes payments to industries outside the economy for materials and intermediate goods imported into the region. Finally, Quadrant IV covers nonmarket transfers of the economy, since it contains the part related to savings and taxes of households, surpluses and deficits of governments and intergovernmental transfers. The quadrant also includes purchases by final-demand sectors from industries outside the region.

		Sectors/Consumer industries						Final Demand <i>(f)</i>	TOTAL
		Sector 1	Sector 2	Sector 3	...	Sector <i>j</i>	...		
Sectors/Productive Industries	Sector 1	(II) Interindustry structure						(I) Consumption patters	
	Sector 2								
	Sector 3								
	...								
	Sector <i>i</i>								
	...								
	Sector n								
Added Value (<i>v</i>)		(III) Incomes						(IV) Non-market transfers	
Imports									
TOTAL									

Source: Own elaboration based on Schaffer (1999)

Figure 1.12. Structure of an Input-Output table.

1.3.2.1. GDP measurement

GDP is a measure of the economic activity in a country and is defined, from an expenditure approach, as the sum of the total value of all services and goods produced in a country in a one-year time span. As has already been said, an IO table captures both the domestic production and final consumption in a country, while also includes imports value.

Thus, from this approach IO data enable us to calculate GDP on the basis of the following values taken from the table: (1) household consumption C, (2) gross private domestic investment I, (3) public investment and sales of goods and services to governments G and (4) net exports —i.e. exports from a sector less the value of imports of the same goods— $E - I$.

$$GDP = C + I + G + (E - I) \quad (\text{eq.1.8})$$

On the other hand, from an income approach, GDP is defined as the sum of gross value added (V) by all resident producers in the economy plus any product taxes

(less subsidies) not included in the valuation of output ($T - S$). These values are included in an IO table.

$$GDP = V + (T - S) \quad (\text{eq. 1.9})$$

1.3.3. Objectives of the Input-Output analysis

At present, the IO model is a widely used economic tool all around the world. The United Nations have promoted this approach as a planning model in developed countries and have designed some common rules to standardize national accounts in order to build similar IO tables (WIOD: World Input-Output Database project 2009-2012).

IO information has been recently understood as an essential part of an economic framework of labour and capital inputs and social and employment accounts associated to the industrial production of each country. Therefore, this model is being applied to analyse the evolution of regional and international flows of goods and services and other more specific issues such as energy consumption or pollution from industrial activity.

At the simplest level, an IO model consists on a system of linear equations accounting for the way in which each sector distributes its product through sales to other sectors and to final demand. Most of the extensions to the basic input-output framework are introduced to incorporate additional information of economic activity, such as evolution over time or space, to accommodate limitations of available data or to connect input-output models to other kinds of economic analysis tools.

IO method offers a wide range of techniques to address the different objectives within the economic analysis, which can be grouped in three research areas (Tarancón 2003):

- Structural analysis: This is focused on studying the productive structure associated with IO tables. This type of analysis seeks to identify the reasons behind changes in the tables' variables over time.
- Simulation/Impact assessment: This part of the IO analysis aims at evaluating the impacts of certain changes in the table's elements on the overall economy. These changes can be interpreted as either changes in productive structure —due to, for instance, technology improvements— or changes in exogenous variables such as household demand.
- Forecasting analysis: The forecasting techniques intend to estimate the IO tables corresponding to the future.

Despite the considerable range of possibilities that IO models offer, it is worth pointing out some limitations when analysing some specific variables due to the fact that either the IO information may be insufficient or there may not be enough disaggregation of IO data for carrying on such analysis. Different ways to overcome such weaknesses have been proposed in previous literature (Alcántara, Del Río y Hernández 2010) either by adding complementary information to the basic IO table or by manipulating the central matrix in the model with the aim to highlighting already existing information which is not liable to be captured without a specific treatment.

These suggestions have led to both extended IO models—combining IO data with other type of data— and hybrid IO models —combining monetary and physical units in different parts of the IO table— (Bullard y Herendeen 1975). Such models have made possible to study issues like emissions and water or energy consumption (for more detail see reviewed works in Section 3.4).

1.3.4. Concepts and basic methods of the Input-Output analysis

1.3.4.1. The Leontief model

As said before, the most basic form of an IO model consists on a linear equation system where each equation shows the way each economic branch sales its

production to the rest of the sectors and to final consumers of the country. Thus, if an economy is structured in n economic sectors —acting as producer and purchaser at the same time —a system with n equations is then defined:

$$\begin{aligned}
 Z_1 &= z_{11} + \dots + z_{1j} + \dots + z_{1n} + f_1 \\
 Z_2 &= z_{21} + \dots + z_{2j} + \dots + z_{2n} + f_2 \\
 &\vdots \\
 Z_i &= z_{i1} + \dots + z_{ij} + \dots + z_{in} + f_i \\
 &\vdots \\
 Z_n &= z_{n1} + \dots + z_{nj} + \dots + z_{nn} + f_n
 \end{aligned} \tag{eq.1.10}$$

that can be expressed in matrix form as follows in equation 1.11, letting i be a $(nx1)$,

$$Z = \begin{bmatrix} Z_1 \\ \vdots \\ Z_n \end{bmatrix}, \quad [z] = \begin{bmatrix} z_{11} & \dots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \dots & z_{nn} \end{bmatrix} \quad \text{and} \quad f = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix}$$

$$Z = [z] i + f \tag{eq.1.11}$$

Z_i represents the total output of sector i ; z_{ij} is the monetary transactions between pairs of sectors (from each sector i to each sector j) —also identified as intermediate sales —; and f_i is the final demand of this sector. The equations of the above system reveal that there exist interdependencies of each sector in all the others because the level of production of a sector depends on both the production of all other sectors (as input requirements) and the level of final demand. Also, as said before, the equilibrium between all industries is achieved because demand equals supply —or the industry sales equal gross output since $Z_i = Z_j$ when $i = j$.

The transactions value allows to identify the percentages or portions of the total inputs of a sector i needed to be purchased to produce one unit of output of the

sector j . Thus, technical coefficients are defined, according to Schaffer (1999), as the division of the row transactions entries by the total supply of the column sector assuming a distinctive period of time (eq. 1.12).

$$a_{ij} = \frac{Z_{ij}}{Z_j} \quad (\text{eq.1.12})$$

When these coefficients are put together the resulting matrix $[A]$ is known as the direct requirements table. So, the system of (eq. 1.13) can be expressed as follows:

$$\begin{aligned} Z_1 &= a_{11}Z_1 + \cdots + a_{1j}Z_j + \cdots + a_{1n}Z_n + f_1 \\ Z_2 &= a_{21}Z_1 + \cdots + a_{2j}Z_j + \cdots + a_{2n}Z_n + f_2 \\ &\vdots \\ Z_i &= a_{i1}Z_1 + \cdots + a_{ij}Z_j + \cdots + a_{in}Z_n + f_i \\ &\vdots \\ Z_n &= a_{n1}Z_1 + \cdots + a_{nj}Z_j + \cdots + a_{nn}Z_n + f_n \end{aligned} \quad (\text{eq.1.13})$$

So, letting final demand be the independent term in each equation, the resulting expression is:

$$\begin{aligned} (1 - a_{11})Z_1 + \cdots + a_{1j}Z_j + \cdots + a_{1n}Z_n &= f_1 \\ a_{21}Z_1 + \cdots + (1 - a_{2j})Z_j + \cdots + a_{2n}Z_n &= f_2 \\ &\vdots \\ a_{i1}Z_1 + \cdots + (1 - a_{ij})Z_j + \cdots + a_{in}Z_n &= f_i \\ &\vdots \\ a_{n1}Z_1 + \cdots + a_{nj}Z_j + \cdots + (1 - a_{nn})Z_n &= f_n \end{aligned} \quad (\text{eq.1.14})$$

In matrix form:

$$\begin{aligned} (I - A) Z &= f \\ Z &= (I - A)^{-1} f \end{aligned} \quad (\text{eq.1.15})$$

Where I is the identity matrix —size $(n \times n)$ —, and $(I - A)^{-1}$ is called the Leontief inverse matrix L , which represents structural interdependences between total both direct and indirect (and possible “induced”) requirements of any industry supplied by other industry’s sectors and by itself. In fact, this matrix is known as the total requirements table or matrix of multipliers, which measure the overall change in the economy as a result of changes in final demand of a given sector.

1.3.4.2. The Ghosh Model

In the classic IO model, the inverse of the Leontief model relates sectorial gross outputs to the amount of final demand – that is, measures the impact on production of final demand changes. By contrast, Ghosh suggested in 1958 an alternative approach relating sectorial gross production to the primary inputs – that is, he proposed a supply-side IO model.

In this case, instead of dividing each column of z_{ij} by the gross output of the sector associated with that column, as the Leontief model makes; each row is divided by the gross output of the sector associated with that row —that is Z_i . Thus, b_{ij} coefficients are obtained (eq. 1.16) representing the distribution of sector i ’s outputs across sectors j , which purchase interindustry inputs from i . Therefore, the direct-output coefficients matrix, matrix B , is defined.

$$b_{ij} = \frac{z_{ij}}{Z_i} \quad (\text{eq.1.16})$$

So, the model results as follows:

$$Z^t = Z^t[B] + V^t \quad (\text{eq.1.17})$$

where $V^t = [v_1, v_2, \dots, v_n]$ is the total value-added expenditure by each sector.

Hence, it is possible to calculate the output inverse matrix $(I - B)^{-1}$ for the Ghosh model (eq. 1.18) whose terms are interpreted as measuring the total value of production that comes about in sector j per unit of primary input in sector i .

$$Z^t = V(I - B)^{-1} \quad (\text{eq.1.18})$$

1.3.5. Extensions of Input-Output model: Structural changes. Demand patterns and its evolution over time.

The review of relevant literature shows different works analysing the sources and reasons that explain a specific sectorial demand structure at any given moment. For instance, Alcántara and Padilla (2009) suggested an hybrid IO subsystems model for studying the productive structure of the different sectors of an economy. The analysis carried out was aimed at decomposing CO2 emissions from service sectors in Spain —year 2000— into different components distinguishing direct and indirect emissions —induced emissions due to the strong pull effect of service activities on other activities of the economy. Other similar example is found in Cosmo et al. (2012) that adopted this approach to reveal the reasons behind sectorial water use in all EU countries.

On the other hand, there exists other group of studies intended to evaluate structural changes and, particularly, to separate the growth of some variables over time. This set of tools facilitate the identification of the factors driving the demand patterns of goods and services and for that purpose they need consistent data sets for two or more years since the matrix of technical coefficients will change over time (Miller and Blair 2009). It is noted that changes in temporal gross outputs may result from either technological changes —in the linkages and interactions between industries/sectors — or changes in final demand over time. The impact of these variations on any output, together with other ones, may be evaluated throughout different models, and one of the most frequently applied techniques is the Structural Decomposition Analysis (SDA). Particularly, this has been used to explain the trends of pollution in some countries and identify the factors driving the levels of emissions from their industries. See, for instance, Mukhopadhyay and Forssell (2005), Llop (2007) and Chang et al. (2008).

Although the common practice is to use the methodology of SDA to explain temporal changes in any factor, it has been also used to analyse distinct patterns of consumption or economic structure that might have their origins in differences in one or another component. Within this context, authors such as Alcántara and Duarte (2004) adopted a spatial approach with a synchronic perspective to examine the position of the different European Union countries as consumers of final energy.

Table 3.1 compiles information regarding some reviewed references that have applied different types of structural techniques.

Table 3.1. Previous literature review on Input-Output Structural Decomposition analysis

REFERENCE	GEOGRAPHICAL COVERAGE	FIELD	ISSUE	STUDY PERIOD
Butnar and Llop (2007)	Spain	Environmet	Environmental IO approach to quantify the changes in the levels of greenhouse emissions caused by exogenous changes in sectorial final demand.	2000
Alcántara and Padilla (2009)	Spain	Environment	Analysis of input-output subsystems to the study of the CO ₂ emissions —direct and indirect— associated to the group of branches of the service sector.	2000
Cosmo, Hyland, and Llop (2012)	27 countries of the European Union	Water consumption	Comparison of patterns of water consumption within Europe through a subsystem input-output model that divides total water use into different income channels within the production system.	2005
Llop (2007)	Spain	Environment	Environmental IO approach to decompose the total changes in Spanish emission multipliers into different components. Separeted evaluation by applying a SDA analysis of the effects of economic structure and pollution intensity.	1995-2000
Chang, Lewis, and Lin (2008)	Taiwan	Environment	IO structural decomposition method to examine the changes in CO ₂ emission over a 15-year	1989–2004

REFERENCE	GEOGRAPHICAL COVERAGE	FIELD	ISSUE	STUDY PERIOD
			period. Identification of the key factors causing the emission changes, as well as the most important trends regarding the industrial development process in Taiwan.	
Mukhopadhyay and Forssell (2005)	India	Environment	Evaluation of air pollution (CO ₂ , SO ₂ , and NO _x) from fossil fuel combustion in India. IO SDA approach is used to find out their sources of changes.	1973–1974 1996–1997
Wood and Lenzen (2009)	Australia	Environment	Analysis of the evolution of the greenhouse gas intensity across the economy as a consequence of temporal changes in production chains.	1995–2005
Fan and Xia (2012)	China	Energy	Application of an hybrid energy IO model to decompose driving factors impacting changes in energy intensity.	1987-2007
Alcántara and Duarte (2004)	14 countries of the European Union	Energy	IO SDA-model to identify the sources of the differences in the energy intensities of the European Union countries. Description of the role that each sector and country plays as an energy consumer.	1995
Wachsmann et al. (2009)	Brasil	Energy	Structural decomposition analysis to analyze the evolution of the energy consumption from industries and households.	1970-1996
Dietzenbacher and Hoekstra (2002)	Netherlands	Economy	Structural decomposition to analyze the effects of technological changes and trade on the sectoral outputs.	1975-1985
Guilhoto et al. (2001)	Brazil and the United States	Economy	Analysis of the changes in the economic structure of two large countries with different levels of development over time.	1958-1977 (US) 1959–1980 (Brazil)

Source: Own elaboration

1.4 Objective and research questions

Based on the above considerations, the main objective of this thesis consists of providing knowledge for explaining road freight transport decoupling trends in Europe and identifying explanatory factors leading to this situation.

The methodology to tackle this goal is based on a Macro analysis aimed at identifying the main drivers of road freight transport demand and their likely effect as inhibitors or enablers of decoupling.

To achieve this central objective, several questions stated in previous sections need to be answered and these are developed in different academic papers.

Is there current evidence of decoupling? or, conversely, can new coupling trends be found in different countries?

The reason behind this research question is that previous literature on road freight transport demand revealed how road freight transport remained stable or even declined under economic growth scenarios in some countries like the United States or the UK; while, in other countries like Sweden, this situation was not so marked.

The observed past evidence of decoupling in some countries between road freight transport and GDP led to different studies trying to define one way of measuring the decoupling level. Decoupling has been usually studied by analysing changes in the “transport intensity” ratio, which measures road transport in tonne-kilometres per unit of Gross Domestic Product (GDP). Therefore, the starting point of this research consists of checking whether decoupling trends have continued during recent years through a similar analysis. Determining both the state of play and the likely potential of decoupling is essential to identify the need for further research in this area through new techniques.

Moreover, GDP has usually been the only socioeconomic variable considered to analyse and forecast road freight traffic demand, but decoupling evidence may lead to the key conclusion that such type of aggregate economic variables are by

themselves unable to explain the evolution of road freight transport demand over the years.

How important are the economic structure and the restructuring processes of economies in a country for the promotion of decoupling?

A good understanding of the nature of the relationship between road transport and the economy is crucial for several reasons. First, because this relationship is supposed to help planners estimate the evolution of road freight transport demand over time. And second, because knowing this relationship will help policy-makers adopt measures to promote sustainable growth since road traffic is responsible for a wide amount of externalities.

Since several developed countries have experienced changes in the structure of their economy toward more service-oriented activities, dematerialization processes are playing a major role in decoupling road freight transport from economic growth. Despite this, little research has been conducted about the impact of such processes on road freight transport trends.

Therefore, addressing this question may help to clarify the relevance of the economic restructuring processes in decoupling. To that end, it is necessary to look for new methods that allow developing this analysis. This research will contribute to prove that Input-Output tables combined with transport information at the macro level may be a useful tool for achieving this goal.

Do sectorial road freight transport intensities partly determine the final decoupling level in a country? How important is the evolution of these ratios over time in road freight transport behaviour?

This section has revealed that one of the variables defining the amount of units of transport moved across countries is the road freight transport intensity ratio (RFTI). Furthermore, many previous studies about decoupling analysed this index in order to define the decoupling level for different countries. It is also highlighted

that different definitions are found for this index. Hence, it is essential to determine the best way of expressing this variable for analysing current decoupling levels.

The analysis developed in this thesis aims to define the impact exerted by the evolution the key drivers on road freight transport trends in order to understand the reasons for coupling/decoupling in Europe. Therefore, this research question needs to be addressed in order to fulfil this core objective. This will be essential to determine if the European logistic system as well as the transport networks and resources has promoted sustainable principles in different countries since the values of RFTI depend on these factors.

Which are the main freight transport drivers that may contribute to increasing or decreasing decoupling levels? What is the current effect of these factors in European road freight transport levels?

This research wonders about suitable explanatory variables for defining road freight transport demand, in order to provide policymakers and stakeholders involved in road management, a useful path to estimate more accurate transport forecasts. .

Decoupling road freight transport from economic growth has been acknowledged by the European Union as a key means to improving sustainability. Therefore, it is crucial to identify both the coupling and decoupling drivers of road freight transport demand in order to determine possible factors that may contribute to reduce road transport in the future without curbing economic development.

Most previous studies have analysed road transport trends only for a single country—often with a focus on the micro-level, whilst this thesis aims at providing a homogenous macro-analysis for different European countries.

The analysis conducted in this thesis will allow finding out similarities and differences between road freight transport trends in Europe by looking at the way different explanatory factors have impacted on road freight transport in different countries.

1.5 Research methodology

The process to achieve the above mentioned objectives and to answer the research questions has been structured into the following stages:

1. Revision of road freight transport trends and transport policies and practice in Europe during the last decades.
2. Revision of previous decoupling studies and methods applied to analyze road freight transport demand evolution at the macro level.
3. Identification of variables influencing road freight transport and data availability to implement the methodological approaches adopted in this research. These variables has been divided into two groups: (1) economic variables like national production or imports/exports and (2) transport and logistics variables such as supply chain structures or modal split.
4. Selection of the country case studies. At this point, these countries had preferably to meet the requirement of showing different trends in road freight transport and economic growth in order to compare similarities and divergences between them. IO information as well as the transport data availability has been an essential condition for the selection of the case studies.
5. Analysis of available base data for building up a dataset containing the variables previously identified. Exploration of the evolution of these variables in the selected case studies.
6. Definition of the analysis methods to go a step further in understanding decoupling causes. A new top-down approach based on Input-Output method combined with transport data is applied in order to identify the key factors driving road freight transport trends in recent decades in Europe and also to provide a cross-country comparison of the results for different European Member States. In addition this methodology is applied to evaluate the likely potential of some transport drivers such as the economic restructuring processes in the promotion of decoupling through simulation analysis.
7. Finally, recording of conclusions and identification of areas for further research.

1.6 Thesis structure

The research questions previously identified were synthesized in academic papers that have been published in international journals included in the Journal Citation Reports (JCR) database and presented in national and international conferences. These papers develop an analysis method aimed at identifying the key drivers of decoupling based on different European Union case studies. Two important implications of this methodology for policy makers and stakeholders involved in the management of road traffic are highlighted. Firstly, new approaches using Input-Output information from a top-down point of view are applied for the first time to the transportation field in order to help explain the evolution of transport demand. And secondly, the cross-country comparison contributes to define the most appropriate decoupling strategies applicable in those countries where road freight transport is still growing at a pace with GDP by looking at the countries with favorable decoupling trends.

Consequently, the thesis is structured into 6 chapters that contain these research papers. The papers are referred to in the text by Roman numerals I to III (see Section 1.13):

- **Chapter 1** is the present introduction. It reviews the recent European road transport trends, summarizes the literature review in the field of decoupling subject and also describes the Input-Output method. This includes a description of the research gaps identified and the main objective of the research.
- **Chapter 2** analyses the state of play of decoupling in the cases of Spain and the United Kingdom, and identifies some key explanatory variables for the observed trends in each country (paper I). Based on these cases this chapter shows the potential impact of the economic restructuring processes in reinforcing decoupling trends. (paper II)

- **Chapter 3** develops a detailed analysis about key drivers of road freight transport demand, and provides an EU-level cross-country comparison in order to explain similarities and differences among them. (paper III)
- **Chapter 4** is a summary of the main conclusions and contributions of the thesis. It also includes future research trends.
- **Chapter 5** includes a compilation of the abbreviations and acronyms used in the research.
- **Chapter 6** lists all the references of the research.

Figure 1. 13. Overall picture of the thesis structure

1.7 List of original publications

This thesis is based on the following papers that have been published to a scientific peer-reviewed journal. As a result there is some overlap in the content between the chapters (papers) which address those research questions previously identified.

- I. Alises, Ana, Jose Manuel Vassallo and Andrés Felipe Guzmán. 2014. “Road Freight Transport Decoupling : A Comparative Analysis between the United Kingdom and Spain.” *Transport Policy* 32. Elsevier: 186-93. doi:10.1016/j.tranpol.2014.01.013.
- II. Alises, Ana and Vassallo, Jose Manuel. The impact of the structure of the economy on the evolution of road freight transport: A macro analysis from an Input-Output approach. *Transportation Research Procedia Elsevier*: 14 (2016) 2870 – 2879. doi: 10.1016/j.trpro.2016.05.404
- III. Alises, Ana and Vassallo, Jose Manuel. “Comparison of road freight transport trends in Europe. Coupling and decoupling factors from an Input-Output structural decomposition analysis.” *Transportation Research Part A: Policy and Practice*, 2015, vol. 82, issue C, pages 141-157. doi: 10.1016/j.tra.2015.09.013

The contents of the papers mentioned above were displayed in national and international contents through the following presentations:

- Alises Pérez, Ana; Vassallo Magro, José Manuel y Guzmán Valderrama, Andrés Felipe (2014). ¿Evoluciona la demanda de transporte de mercancías por carretera de acuerdo al PIB? Análisis de los factores que han generado el desacoplamiento actual en países europeos. “*XI Congreso de Ingeniería del Transporte, CIT2014*”, 9 al 11 de junio de 2014, Santander, España. ISBN 978-84-697-0359-5. pp. 1-16.

- Alises Pérez, Ana y Vassallo Magro, José Manuel (2014). Relación entre la demanda de transporte de mercancías por carretera y la economía. Resultados de un análisis estructural con tablas input-output. *"XVIII Congreso Panamericano de Ingeniería de Tránsito, Transporte y Logística, PANAM 2014"*, 11 al 13 de junio de 2014, Santander, España. ISBN 978-84-617-0085-1. pp. 1-16.
- Alises Pérez, Ana; Vassallo Magro, José Manuel y Aymerich, Mario (2015). *Comparison of Road Freight Transport Trends in Europe: Results of Input-Output Structural Decomposition Analysis*. "Transportation research Board 94th Annual Meeting", January 11-15, 2015, Washington, D.C., Washington. pp. 1-15.
- Alises, Ana and Vassallo, Jose Manuel. The impact of the structure of the economy on the evolution of road freight transport: A macro analysis from an Input-Output approach. "6th European Transport Research Arena Conference. Moving forward: Innovative Solutions for Tomorrow's Mobility." 18-21 April 2016 Warsaw, Poland

2. DECOUPLING ANALYSIS IN SPAIN AND THE UNITED KINGDOM: STATE OF PLAY AND LIKELY POTENTIAL LEVELS

This chapter contains a comparisson analysis about the relationship between tonne-kms and GDP achieved last years in the United Kingdom and Spain. It also provides an overview of the divergences and similarities in the evolution of the economy and of the national and sectorial road freight transport intensities in both countries.

Data sources of this analysis consist of national Input–Output (IO) tables collected from the World Input–Output Database (WIOD) and data series of transport measurements sorted by commodity group in each country obtained from EUROSTAT Database.

Firstly a decomposition analysis of the evolution of the ratio [tonne-kms/GDP] is developed in order to explain the higher levels of decoupling in the UK in comparisson with Spain (paper I). According to Dietzenbacher and Los (1997), if any factor —y— can be expressed by the product of n variables — $x_1, x_2, \dots, x_n$ —, the observed changes over the period 0-1 leads to the following decomposition:

$$\begin{aligned}\Delta y = & \left(\frac{1}{2}\right) (\Delta x_1) [(x_2^0 \dots x_n^0) + (x_2^1 \dots x_n^1)] \\ & + \left(\frac{1}{2}\right) [x_1^0 (\Delta x_2) (x_3^1 \dots x_n^1) + x_1^1 (\Delta x_2) (x_3^0 \dots x_n^0)] + \dots \\ & + \left(\frac{1}{2}\right) [(x_1^0 \dots x_{n-2}^0) (\Delta x_{n-1}) x_n^1 + (x_1^1 \dots x_{n-2}^1) (\Delta x_{n-1}) x_n^0] \\ & + \left(\frac{1}{2}\right) [(x_1^0 \dots x_{n-1}^0) + (x_1^1 \dots x_{n-1}^1)] (\Delta x_n)\end{aligned}\tag{eq.1.18}$$

It is highlighted that the two case studies were selected as long as their heterogeneity in terms of road transport trends and decoupling levels (see Figure 2.1 and 2.2).

ANALYSIS OF THE KEY DRIVERS FOR ROAD FREIGHT TRANSPORT DECOUPLING IN EUROPE FROM AN INPUT-OUTPUT APPROACH

Source: Own elaboration on the basis of EUROSTAT data

Figure 2.1. Growth of real GDP, road tonnes, road tonne-kms and veh-km in Spain (index 1999=100): 1999–2011

Source: Own elaboration on the basis of EUROSTAT data

Figure 2.2. Growth of real GDP, road tonnes, road tonne-kms and veh-km in the UK (index 2004=100): 2004–2011

From the results of the previous analysis, this chapter also conducts a simulation exercise in order to evaluate the impact of the restructuring of the national economy –towards a full dematerialization or a full materialization– on the elasticity values $[\Delta \text{veh-km} / \text{veh-km} / \Delta \text{GDP} / \text{GDP}]$.

To fulfil this objective, an extended Input-Output model has been adopted since Input-Output tables combined with transport information at the macro level may be an useful tool for explaining freight transport trends.

This chapter includes two papers that have been published as:

- I. Alises, Ana, Jose Manuel Vassallo and Andrés Felipe Guzmán. 2014. “Road Freight Transport Decoupling : A Comparative Analysis between the United Kingdom and Spain.” *Transport Policy* 32. Elsevier: 186-93. doi:10.1016/j.tranpol.2014.01.013.
- II. Alises, Ana and Vassallo, Jose Manuel. The impact of the structure of the economy on the evolution of road freight transport: A macro analysis from an Input-Output approach. *Transportation Research Procedia Elsevier*: 14 (2016) 2870 – 2879. doi: 10.1016/j.trpro.2016.05.404

Road freight transport decoupling: A comparative analysis between the United Kingdom and Spain

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ABSTRACT

Economic growth has traditionally been linked to road freight transport demand, leading to a steady rise in social and environmental impacts. Concern about this problem has caused the EU to promote a decoupling strategy aimed at boosting sustainable development in European countries by improving the efficiency of transport systems without curbing economic growth. Over the last few years empirical evidence in some countries such as the United Kingdom has shown an increase in GDP while the volume of road freight traffic has remained stable or even decreased. This paper compares recent decoupling trends by analyzing the evolution of road tonne-kms/GDP relationship in the United Kingdom and Spain from 1999 to 2007. This comparison seeks to identify the main differences and key drivers of decoupling in both countries. We first provide an overview of the divergences between both economic structures and levels of road transport intensity. Then we conduct a decomposition analysis in order to identify the variables that explain the evolution of truck traffic per unit of GDP in each country. The results show that the increasing share of services in GDP has substantially contributed to decreasing road transport demand in both cases. Changes in road transport intensity due to improvements in logistic and supply chain management have been more successful in the UK than in Spain.

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1. Introduction

In most industrialized countries there has been a strong positive relationship between economic and transport growth, and specifically road transport. The growth of road transport activity has been the cause of a number of environmental and social problems. Greenhouse gas emissions from human activity, particularly road transport, produce global warming which is likely to cause an increase in natural disasters and negative consequences for property, infrastructure and the natural environment. In addition, transport congestion has increased in many countries, affecting urban areas and leading to high social costs.

The current trend in numerous European countries towards enhancing sustainability, supported by the European Union (EU) as a means of tackling these environmental and social problems, promotes the decoupling of road transport growth from the economic development.

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The subject of ‘decoupling’ has been widely treated by policy reports. For instance, it was the focus of the Standing Advisory Committee on Trunk Road Assessment (SACTRA) report in the United Kingdom in 1999, and has also been discussed in political documents such as the European White Paper on transport policy in 2001 (European Commission, 2001b). In this paper, the EU promoted a decoupling strategy as a key means to reduce the external costs of road transport by promoting GDP growth without increasing transport volumes. The EU also supported a research project which proposed the ultimate prioritization of policy measures based on their likely effectiveness in reducing road freight transport-related externalities (European Commission, 2003). EU Member States were encouraged to meet this challenge, for instance, by establishing higher costs for road freight transport, in a bid to stimulate improvements in logistics management and transfer some traffic volumes from road to more competitive and efficient modes. All these measures have the main goal of increasing transport efficiency through the internalization of the negative side-effects of transport (European Commission, 2001a).

Several researchers have studied decoupling by means of an approach that evaluates changes in road transport intensity. This ratio – road tonne-kms per unit of GDP – measures the link between the economy and road transport activity. Breaking or weakening this link, by applying actions or policies designed to

meet the objectives of the EU's sustainable development strategy, may change the historical values that have remained stable over a considerable period in each country. Furthermore, some countries have been undergoing a transition to more service-oriented economies, and as a consequence their economic growth has become progressively detached from transport demand, thus contributing to decoupling.

The aim of this paper is to review the trends for road transport and GDP growth in two case studies: the United Kingdom (UK) and Spain, and to analyze the reasons for their divergences. Specifically, the research focuses on determining the level of decoupling and on identifying the key drivers underlying its evolution over the years in each country through a decomposition analysis. We chose these two countries for several reasons. The UK is one of the European countries in which decoupling has been most notable, whereas Spain has followed a very different trend. Finally both the UK and Spain are large countries with limited borders for the entry of freight by road, and thus cross-country traffic and major ports have a little effect on freight transport.

The paper is organized as follows. After the introduction, Section 2 reviews the existing literature on decoupling, and explains the main contributions of this research to the state of the art. Section 3 provides a comparison of the level of decoupling in both case studies, identifies the key drivers of decoupling and analyzes their trends throughout the period of analysis. This section also highlights the contributions of each economic sector to the global trends. Finally, Section 4 points out the main conclusions of this research.

2. Links between road freight transport and economy

It is widely accepted that transport accounts for a significant share of the GDP in industrialized countries. For this reason, the correlation between tonne-kms and GDP, known as “coupling”, has traditionally been applied to forecast trends in freight transport demand, although some authors, such as McKinnon and Woodburn (1996), NEI (1997) and Kveiborg and Fosgerau (2007), claim that the factor to be taken into account is industrial sector production rather than GDP.

Despite the linearity assumptions in the relationship between GDP and transport demand – measured in tonne-kms – supported by authors such as Bennathan et al. (1992), at present, transport demand is rising more slowly than economic growth. Recent research has developed various empirical studies analyzing the historical evidence for decoupling and its future potential (i.e. Banister and Stead (2002) and Gilbert and Nadeau (2002)). Possibly one of the most significant contributions is the European ‘REDEFINE’ project (NEI, 1997), which examined road freight transport trends in five European countries between 1985 and 1995 and concluded that rather than a decoupling there had been a “recoupling” of road freight transport growth and GDP in most countries, and that these trends were likely to continue.

In contrast, the analysis of transport trends in several research works led to clear evidence of decoupling in countries such as Japan, the United States (OECD, 2003) and the United Kingdom (McKinnon, 2007). For instance, in the UK, GDP rose by 21% between 1997 and 2005 while total tonne-kms grew by only 8%, being the divergence of road tonne-kms and GDP trends over this period even more notable.

According to McKinnon (2007), the different decoupling rates among countries depend on the share of “intensive industrial sectors” in the whole economy. This implies that some sectors such as agriculture or mining demand more tonne-kms in their

production processes than service sectors. As services expand their share of total GDP, this leads to a higher economic growth than transport growth (Åhman, 2004). Supply chain management may also change the “transport intensity” of industrial sectors by taking advantage of economies of scale or improving technology and logistics systems (Lehtonen, 2008).

The concept of “transport intensity” is defined as the ratio of freight transport to economic growth, i.e., tonne-kms per unit of GDP. Thus a decrease in this ratio points to a lower demand for freight transport services relative to GDP. The concept of “decoupling” refers to a change in the historically constant intensity (Åhman, 2004).

Empirical studies have shown that transport intensities substantially diverge among countries. Between 1975 and 1990, differences were found in patterns of transport intensity in European countries, and these figures were compared with the European Union average (Stead, 2001). The main conclusion of this study was that the stage of economic and social development influences the value of transport intensity and this measurement depends on economic structure, topography, geography, size, land uses, socio-economic factors and transport infrastructure. The World Bank conducted a cross-sector study, using 1989 data, of a sample of 33 countries at different stages of development in order to analyze decoupling by evaluating the evolution of transport intensity (Bennathan et al., 1992). The study demonstrated that, although the relationship between GDP and road tonne-kms was extremely close, there were differences between rich and less developed countries. This gap is even more notable for road freight transport intensities (SACTRA, 1999).

As can be seen, freight transport demand is influenced by a wide set of factors. A detailed comparison of two countries such as the United Kingdom and Spain with a different economic structure and different trends in road freight transport intensity could shed some light on understanding different transport decoupling trends. In view of the fact that some of the previous studies on decoupling mentioned in this section were conducted on an aggregate level, this paper contributes to the literature by developing a more detailed analysis sorted by commodity groups. In addition, at present, no decomposition analysis has been developed to explain the main divergences in road transport between two different countries.

3. Decoupling economic activity and transport growth: the state of play in the United Kingdom and Spain

In recent decades the relationship between GDP and road tonne-kms has changed. This contrast is particularly notable in countries such as the UK and Spain, where different levels of decoupling can be observed, as shown graphically in Fig. 1. While the growth of real GDP in the period 1999–2007 led to a 95% rise in road freight transport in Spain, the volume of tonne-kms decreased by 19% in the United Kingdom, where economic growth was 87% measured in current U.S. dollars.

From the literature review, we have identified two key factors that should be considered to explain the evolution of decoupling: (1) the evolution of the structure of the economy caused by changes in the share of productive sectors in the total GDP; and (2) the rates of road transport intensity by sector.

Let RFT_C be the total road freight transport in the country measured in tonne-kms, GDP_C the Gross Domestic Product of the country C , RFT_{iC} the road freight transport demand of each industry i and GDP_{iC} the Gross Domestic Product given by each sector. So, being GDP_{iC}/GDP_C the sectorial share of GDP of each industry and RFT_{iC}/GDP_{iC} its road freight transport intensity, it leads to define the relationship between road transport volume and GDP in a country through the following

Note: Real GDP growths or declines (%) are based upon U.S. dollars real GDP variations. Yearly US\$ GDP values are obtained by converting national currency GDP values to US\$ using market exchange rates (yearly average)

Fig. 1. Growth in real GDP and road tonne-kms in the United Kingdom (a) and Spain (b) (index 1999=100): 1999–2007.

equation. We want to note that the productive structure of the country is organized in n industries.

$$\frac{RFT_C}{GDP_C} = \sum_{i=1}^n \left(\frac{RFT_{i,C}}{GDP_{i,C}} \times \frac{GDP_{i,C}}{GDP_C} \right) \quad (1)$$

From here on, this paper analyzes the evolution of two terms on the right-hand side of this equation over time, and how they have influenced decoupling trends in both the UK and Spain. The research uses data from 1999 to 2007. The information on road freight transport demand – data series of tonne-kms sorted by commodity group in each country – was obtained from EUROSTAT (Eurostat, 2013). This information was confirmed and completed with statistics from the UK Department for Transport for 2013 (Transport Statistics, 2013). Economic data were collected from the Input–Output (IO) tables compiled by the World Input–Output Database (WIOD, 2013). This dataset provides the IO tables at current prices in US\$ according to the national accounts. National currencies were converted using the US\$ exchange rate and the fixed Euro rate for the Euro-zone countries.

To homogenize the economic and transport data, we have aggregated the original IO tables into 11 groups representing the main areas of economic activity. This aggregation was done according to the commodity groups in the transport dataset. The 11 industries are the following: (1) Food industry, (2) Mining, (3) Textile sector, (4) Wood products, (5) Paper, Printing and Publishing products, (6) Energy: Fuel and power products; (7) Chemical products, (8) Machinery and transport equipment, (9) Manufacturing products, (10) Construction, and (11) Services. The first 10 sectors are transport-intensive sectors, whereas the 11th is not.

Data until 2007 was used due to the lack of complete information by commodity after this year. For more recent information we have identified gaps in the tonne-kms dataset for certain sectors like construction. An additional advantage of using this period is that it avoids the impact of the economic recession in Europe, as the distinctive nature of the economic downturn might distort the final results. The period 1999–2007 is sufficiently representative to show the divergences for the two case studies.

3.1. Economic structure and intensive sectors

As we have noted before, certain economic sectors demand more road tonne-kms per US\$ of GDP than others. Specifically, service activities generate fewer road tonne-kms relative to their output than non-service activities such as manufacturing, agriculture or construction, which show higher road freight transport intensities. Therefore, it seems essential to look at the economic structure of a country in order to identify the key sectors driving road freight transport demand.

Fig. 2. Input–output transaction table (2007) for the United Kingdom (a) and Spain (b). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 2 gives an overview of the main economic sectors in the national output in both economies—the UK and Spain—by showing graphically the national 2007 IO tables, with economic transactions among industries shown in US\$. These IO tables reflect the inter-industry relationships within a country, and consider the whole economy organized into 35 sectors. The first 18 sectors in the

Table 1

Sector shares of GDP in both UK and Spanish economies in 1999 and 2007 and total change by sector.

Industry class	United Kingdom			Spain		
	1999 (%)	2007 (%)	Total change 1999–2007 (%)	1999 (%)	2007 (%)	Total change 1999–2007 (%)
1. Food	3.74	2.91	–0.83	7.05	4.99	–2.06
2. Mining	4.77	4.10	–0.67	4.54	4.25	–0.28
3. Textile	0.92	0.35	–0.56	1.50	0.74	–0.76
4. Wood	0.28	0.25	–0.03	0.46	0.35	–0.11
5. Paper&Printing	2.45	1.60	–0.86	1.57	1.33	–0.24
6. Energy	2.46	2.66	+0.20	2.72	2.80	+0.08
7. Chemistry	2.96	2.15	–0.81	2.72	2.22	–0.50
8. Machinery	6.42	3.71	–2.71	5.19	4.00	–1.19
9. Manufacturing	0.82	0.56	–0.26	0.96	0.75	–0.21
10. Construction	5.50	6.20	+0.70	7.91	11.96	+4.05
11. Service	73.42	75.51	+2.09	65.38	66.60	+1.22
Total	100.00	100.00		100.00	100.00	

original tables (indicated with a yellow background in the figure) are transport-intensive industries, while the others are service sectors. A first look at this figure shows that monetary transactions between service sectors (red bars in either the UK or Spanish graphs) make the most important contribution to the UK economy. In contrast, the main economic sector in Spain's national output is construction (the highest green bar). This graph shows how internal relationships within the construction industry – the construction companies acquiring goods or services from other companies in this industry – represent the most important business transaction in Spain. This is likely caused by the growing trend of subcontracting within this industry. To conclude, it is evident that construction-related businesses were responsible for a high percentage of economic growth in Spain over this period due to its great weight in the whole economy.

In order to obtain a more simplified overview of the economy of both countries, Table 1 shows the evolution and the weight of the industries considered in the whole economy as a share of the GDP during the period of analysis in both the UK and Spain. As we have noted before, this information is obtained by aggregating the information contained within the IO tables from 35 down to 11 sectors.

This table shows that although services have had a notable growth in both British and Spanish economies over the last decades, there are still clear differences between the economic structures of these countries and their evolution over time. While services have a greater weight in the UK economy, and they rose by more than 2% between 1999 and 2007 – reaching a total GDP share of 75.51% in 2007 – the construction industry is particularly significant in Spain, representing more than 11% of the economy in 2007 and increasing more than 4% over the analysis period. This industry requires supplies from the construction industry itself, and from other interrelated industries such as manufacturing, mining and wood. As a result, Spain's recent economic growth has required a higher movement of goods and thus an increased transport demand. As a consequence it may be concluded that the importance of the construction sector in Spain has likely contributed to curbing decoupling in this country.

3.2. Road freight transport intensity

It is important to note that in recent years numerous industries have made considerable efforts to improve their logistical performance by optimizing their fleets, managing their routes, and designing logistics centers, and these measures have influenced road freight transport intensity (RFTI) values. RFTI measures the amount of goods (commodity in tonne-kms) moved by road for a particular industry in a country per unit of its GDP. As indicated in previous sections, this ratio may adopt different values across industries and countries due to the specific characteristics of each industry or the

particular features of each country. Thus, a cross-sector analysis of RFTIs may lead to a deeper understanding of decoupling.

According to McKinnon (2007), RFTI values depend on some key ratios that may vary across different countries. If these ratios remained stable, RFTIs would have a fixed value and transport growth would only depend on the country's level of production. However, RFTIs usually vary in a different way over time across countries due to differences in the organization of supply chains or the evolution of road share compared to other modes.

Fig. 3 shows the framework for the assessment of road freight transport demand measured in tonne-kms in relation to industrial production measured in monetary units. The monetary production of each industry is converted to transport volume using four factors: (1) the average value density, (2) the handling factor, (3) the modal split and (3) the average length of haul.

First, the inverse value density – ratio of average weight of goods to the monetary GDP value (tonne/\$) – provides the total tonnes of each category of goods for a sectorial monetary production. Changes in this ratio are influenced by the development of new product design techniques and manufacturing processes, and also by the current trend towards using lighter materials. Therefore product design and packaging attributes like mass or volume may affect value density and the value of RFTI.

The handling factor converts the physical weight of the goods produced into freight tonnes lifted by all transport modes. This ratio refers to the number of times a product is lifted between origin and destination of the supply chain – from its production to the point where the good is consumed – for each type of commodity. Hence changes in the handling factor of individual goods over time are substantially influenced by logistical changes.

If information is available on the modal split, the total tonnes lifted can be assigned to a specific transport mode. Finally, if the value of the average length of haul is known, the road tonnes lifted can easily be transformed into tonne-kms. This last measure is strongly influenced by the average distance between origin and destination within the supply chain, as well as by the choice of truck route for each journey.

According to this methodology, we are able to untangle the RFTI of each economic activity area i as follows:

$$\begin{aligned}
 RFTI_i &= \frac{\text{tonnes} - km_{road,i}}{GDP_i (\$)} \\
 &= \underbrace{\frac{\text{tonnes}_{produced,i}}{GDP_i (\$)}}_{\text{inverse of value density}} \times \underbrace{\frac{\text{tonnes}_{lifted,i}}{\text{tonnes}_{produced,i}}}_{\text{handling factor}} \times \underbrace{\frac{\text{tonnes}_{lifted,road,i}}{\text{tonnes}_{lifted,i}}}_{\text{modal share}} \times \underbrace{\frac{\text{tonne} - kms_{road,i}}{\text{tonnes}_{lifted,road,i}}}_{\text{length of haul}}
 \end{aligned}
 \quad (2)$$

Once the methodology has been defined, this section explains the changes in the RFTI index for both the UK and Spain. Table 2

Fig. 3. Relationships between economic and freight transport measurements, key ratios and factors.

Source: adapted from McKinnon (2007).

Table 2
Total changes in economic and transport measurements and logistical ratios in the United Kingdom and Spain from 1999 to 2007.

	United Kingdom 1999–2007	Spain 1999–2007
GDP	+87%	+134%
Inverse value density $\times$ Handling factor	–38%	+26%
Tonnes lifted	+23%	+179%
Modal split	–1.2%	+3.7%
Road tonnes lifted	+18%	+195%
Length of haul	–31%	–34%
Road tonne-kms	–19%	+95%
Road transport intensity	–57%	–17%

shows an overview of the evolution of the main global economic and aggregated transport units in both countries – GDP, tonnes lifted, road tonnes lifted, and road tonne-kms – along with the value of the ratios explaining the changes.

As there is no dataset available that allows us to estimate the inverse value density, we have redefined the total RFTI according to Eq. (3) for each country using three ratios instead of four, aggregating the two first ratios previously defined by Eq. (2):

$$RFTI_C = \frac{\text{tonnes} - \text{km}_{\text{road},C}}{GDP_C(\$)}$$

$$= \frac{\text{tonnes}_{\text{lifted},C}}{GDP_C(\$)} \times \frac{\text{tonnes}_{\text{lifted,road},C}}{\text{tonnes}_{\text{lifted},C}} \times \frac{\text{tonne} - \text{kms}_{\text{road},C}}{\text{tonnes}_{\text{lifted,road},C}} \quad (3)$$

The results displayed in Table 2 show that the differences in road transport trends between the two countries are mainly caused by the evolution of the ratio [Value density $\times$ Handling factor] that decreased in the UK but increased in Spain. The restructuring of the economy prompted changes in the type of goods produced and moved in each country, and consequently in the average value density. Construction commodities have often low value densities and they usually require numerous trips—which implies high handling factors. Consequently, the growth of the construction activity can be identified as a main reason to explain the observed trends in Spain—a higher growth of tonnes lifted than GDP growth compared to the UK. Moreover, Table 2

shows how the shift from road to other modes has contributed to enhance decoupling in the UK, while the reverse occurred in Spain.

In spite of these divergences, we have found some common patterns in both cases. Supply chains in both Spain and the UK have tended to reduce distances, thus contributing to decoupling. This represents a change in trend compared to the results of Kveiborg and Fosgerau (2007) for the three decades preceding the study period in this paper, who reported increasing average haulage lengths in the 1970s, 1980s and 1990s in many European countries. It is noted that this new trend in Spain is also partly attributable to the construction activity as construction materials haulages imply shorter distances than the ones for other commodities.

Table 3 shows a comparison of the RFTI for the 11 industries into which we have classified the economy in Spain and the UK by providing figures explaining the total changes observed in this value and in the related ratios shown in Eq. (3), between 1999 and 2007.

This disaggregation provides a clearer overview of the logistical performance of different commodities in the UK and Spain by identifying the industries whose performance improved or deteriorated over the years. The analysis is helpful in identifying which industries still have room for improvement in their decoupling level, and consequently an ability to reduce externalities.

This cross-sector analysis shows that supply chain organization and logistical performance for different commodity classes have led to notable changes throughout the period of analysis. All the UK economic sectors with the exception of the paper industry have lower RFTIs in 2007 compared to 1999, and some have seen reductions of over 40%. However, unlike the UK, certain industries in Spain have recorded a rise in their RFTIs so these results are consistent with a study by Arvis et al. (2007), which placed the UK 17 positions ahead of Spain in the Logistics Performance Index ranking.

3.3. Decomposition analysis

After analyzing in detail the evolution of both the GDP structure and the RFTI for each case study, this section of the paper contains a decomposition analysis that quantifies the main

Table 3

Total changes in road transport intensities by sector and evolution of related key ratios in the United Kingdom and Spain.

Industry class	RFTI (tons-km/GDP)		Change in RFTI (%)	Change in <i>tonnes_{shifted}</i> /GDP (%)	Change in modal split (%)	Change in the length of haul (%)
	1999	2007				
United Kingdom						
1. Food	1.18	0.61	−48.28	−14.91	−0.38	−28.60
2. Mining	0.37	0.22	−40.23	−26.74	−0.04	−19.84
3. Textile	2.05	1.91	−7.02	+66.79	± 0.00	−39.44
4. Wood	1.21	0.50	−58.93	−28.01	± 0.00	−31.03
5. Paper&Printing	0.02	0.03	+23.97	−1.06	± 0.00	−14.21
6. Energy	0.29	0.09	−66.59	−26.26	+0.92	−31.10
7. Chemistry	0.31	0.15	−52.44	−10.28	± 0.00	−28.45
8. Machinery	0.15	0.11	−29.37	+10.77	+0.39	−35.62
9. Manufacturing	0.38	0.23	−38.72	−5.75	−0.28	−14.66
10. Construction	0.15	0.06	−59.20	−41.12	−2.87	−19.62
11. Service	0.04	0.01	−59.09	−36.66	−0.93	−34.85
Spain						
1. Food	1.21	1.10	−12.64	+8.19	+0.67	−7.02
2. Mining	1.38	0.91	−2.48	+67.75	+0.01	−39.29
3. Textile	0.08	2.22	+82.54	+57.21	+0.30	−1.39
4. Wood	0.32	0.67	−51.41	−23.05	+0.29	−36.81
5. Paper&Printing	0.61	0.09	+15.50	+47.08	+5.71	−24.31
6. Energy	0.28	0.21	−35.39	−29.25	+0.20	−15.09
7. Chemistry	0.64	0.50	−16.95	+4.18	+0.93	−21.80
8. Machinery	0.21	0.38	+36.32	+56.64	+0.03	−12.83
9. Manufacturing	0.04	0.48	−25.73	−17.11	−1.81	−10.40
10. Construction	0.22	0.15	−29.02	+7.91	+1.23	−34.55
11. Service	0.04	0.03	−29.52	−6.25	+1.52	−20.73

contributions to decoupling of this set of factors. This decomposition is interpreted as follows: each term captures how much of the increase or decrease in tonne-kms/GDP elasticity in the UK and Spain from 1999 to 2007 can be attributed to changes in each explanatory variable, while keeping the values of the rest of variables constant.

Using subscripts 0 for the base year 1999 and 1 for each of the following years in the study period, the decomposition of the change in the ratio [tonne-kms/GDP] from 0 to 1 into different contributions is given by Eq. (4) according to Dietzenbacher and Los (1997):

$$\Delta \left(\frac{RFT}{GDP} \right)_{0-1} = \sum_{i=1}^n \left[\underbrace{\frac{(1/2)(\Delta W_i)_{0-1}(RFT_{i,1} + RFT_{i,0})}{GDP \text{ structure change effect}}}_{\text{Road freight transport intensity change effect}} + \underbrace{(1/2)(W_{i,1} + W_{i,0})(\Delta RFT_i)_{0-1}}_{\text{Road freight transport intensity change effect}} \right] \quad (4)$$

where W_i is the weight of each sector i in total GDP, and RFT_i its road freight transport intensity. As before, we have considered that the economy is split into n sectors.

The first term on the right-hand side of the equation shows the sectorial contribution to decoupling – change in the tonne-kms/GDP ratio – due to the change in the share of GDP of each industry in national GDP from base year 0 to year 1. The second term shows the contribution of the variation in RFTI in this sector during this period due to the logistical performance of the supply chains. The repetition of this analysis for each industry gives the total contribution of each economic sector to decoupling.

The implementation of this methodology for each country and sector enables us to determine the differences between the two case studies and identify the key sectors that contribute to the two causes of decoupling. Table 4 shows the final contributions obtained for the total changes by sector for the GDP structure (see Table 1) and road transport intensity (see Table 3).

According to the results of this analysis, the food industry, services, chemistry industry, and machinery turn out to be the key

sectors accounting for the evolution of road transport demand in both countries. Food industry made the highest contribution to decoupling in both Spain and the UK. In Spain this contribution was primarily due to the change in its share of GDP, while in the UK this trend can be largely attributed to logistical improvements in the supply chain. Service sectors, which are not transport-intensive, played an important role in decoupling in both countries due to their high share of GDP in both the UK and Spain. On the other hand, sectors such as textiles and mining contributed significantly to decoupling in the UK, although they had a negligible impact in Spain.

From these results, by aggregating all sectorial contributions, we can explain the evolution of the road freight transport/GDP ratio on the basis of both the evolution of the share of different industries in the GDP, and logistical changes in the country. These results explain the decoupling trends in the UK and Spain from 1999 to 2007. Fig. 4 shows them graphically.

As can be seen the decoupling of transport demand from GDP is confirmed in both cases, although this was more notable in the UK than in Spain. In the UK the total decrease was around 57% while in Spain this ratio did not begin to decrease until 2003 and by the end of this period the road transport to GDP ratio had only fallen by 17%.

The figure emphasizes that changes in the structural composition of GDP were the dominant factor to promote decoupling in Spain, while in the UK the reduction in RFTI has had the most pronounced effect to slow down the road freight transport demand growth. This has been decisive to establish the marked differences between decoupling trends in both countries.

4. Conclusions

The issue of decoupling has attracted considerable attention in Europe over the last few years. Researchers and practitioners are working towards a better understanding of the key challenges in order to help governments adopt specific actions that are likely to contribute to implement successful decoupling strategies and

Table 4

Contributions to road freight transport/GDP change by industry from 1999 to 2007 in the United Kingdom and Spain.

Industry class	United Kingdom			Spain		
	Total contribution (%) [A+B]	Contribution of change to GDP share (%) [A]	Contribution of change to RFTI (%) [B]	Total contribution (%) [A+B]	Contribution of change to GDP share (%) [A]	Contribution of change to RFTI (%) [B]
Food	−16.75	−4.20	−12.54	−6.18	−9.48	+3.28
Mining	−5.43	−1.01	−4.41	−0.70	−1.14	+0.43
Textile	−7.68	−7.08	−0.60	−0.81	−5.80	+4.98
Wood	−1.39	−0.11	−1.27	−1.75	−0.48	−1.27
Paper&Printing	−0.07	−0.15	+0.08	−0.01	−0.09	+0.08
Energy	−2.88	+0.38	−3.25	−1.32	+0.09	−1.41
Chemistry	−3.83	−1.09	−2.74	−2.33	−1.22	−1.12
Machinery	−3.70	−2.19	−1.50	+0.33	−1.75	+2.08
Manufacturing	−4.91	−2.81	−2.09	−0.84	−0.52	−0.63
Construction	−2.96	+0.68	−3.64	+0.56	+3.33	−2.78
Service	−11.32	+0.95	−12.26	−3.39	+0.19	−3.57
Total	−57.15	−14.32	−42.83	−16.78	−16.87	+0.08

Fig. 4. Contribution to road freight transport/GDP decoupling in the period 1999–2007 in the United Kingdom (a) and Spain (b). Base year 1999.

ensure sustainable development. Empirical evidence shows how recent transport demand has been rising at a lower rate than GDP in several European countries showing marked signs of this trend. This paper contributes to this body of knowledge by comparing the levels of decoupling in the UK and Spain. The analysis explains why road freight transport appears to have grown more slowly than GDP over the period from 1999 to 2007 in each country, and also clarifies the main reasons for the higher rate of decoupling in the UK than in Spain.

We found that the most important drivers of decoupling were the changes in both the share of different industries within GDP and the evolution of road transport intensity. The decomposition analysis in this paper has demonstrated that the most important driver for decoupling in the UK was the reduction of RFTI. However decoupling in Spain, which was much lower than in the UK, has mostly been driven by changes in the structure of the economy. Both Spain and the UK are moving towards more service-oriented economies, and are depending increasingly less on transport-intensive sectors like agriculture. However, the impact of the growth of the construction sector in Spain contributed to curb decoupling by increasing the tonnes lifted.

The reduction of road freight transport intensity is the result of an interaction of factors which include manufacturing processes, the structure of the supply chain, logistical and technological improvements, and the management of transport resources primarily designed to improve overall efficiency in the movement of goods. This paper demonstrates that the main factor currently contributing to the reduction of RFTI is the reduction of haulage distances throughout the period of analysis. This could be partly due to the trend towards promoting hub and mixed land-uses

approaches that ultimately decrease the average length of haul. Additionally to these logistical improvements, this trend has been mightily caused in Spain by the increase of construction materials haulages that imply shorter distances than the trips for other commodities.

Unfortunately, this positive trend towards improved decoupling has been partly offset by trends in the opposite direction. For instance, in Spain the modal share of road transport increased throughout the period of analysis. The results of this paper show that the EU policy aimed at transferring freight from roads to cleaner modes has not been as effective as expected in promoting decoupling. The findings show that the road mode has continued to account for a very large proportion of freight transport in both countries, and has even risen in Spain.

All the results of this research confirm that decoupling is already a fact in certain European countries, and may contribute to promoting sustainable development both in Europe and in a number of other countries. This research also points to the conclusion that aggregate economic variables such as global GDP are alone unable to explain the evolution of road transport demand over the years. Other factors such as the structure of the economy, haulage distance, organization of the logistical chain, size of trucks, and modal split must be seriously considered when estimating road freight transport.

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The impact of the structure of the economy on the evolution of road freight transport: a macro analysis from an Input-Output approach

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Abstract

Understanding the link between transport and the economy has been of the greatest concern among researchers and practitioners. This research explores the impact of the economic restructuring processes in the aggregate road freight transport demand. We develop a simulation exercise of two alternative economic scenarios over the period 1999–2011 in Spain and the UK by means of an extended Input-Output model. This approach allows us to calculate the elasticity range of vehicles-km to GDP depending upon the types of economic activity developed in these countries and their dematerialization level. The results confirm that the transition to more service-oriented economies implies much lower transport requirements, as has been the case in the UK. Furthermore, the comparison of the two countries has contributed to highlight the importance of other set of non-economic variables, related to technological, logistics and modal factors in the definition of final road freight transport demand.

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1. Introduction

For decades researchers and practitioners have taken for granted the link between economic growth and freight transport demand. However, in several countries the historical elasticity values between transport and the economy have been radically changing over the last few years (Gilbert and Nadeau (2002) and Sorrell et al. (2012)). This fact demonstrates that the real cause-effect relationship between these two variables is not yet fully known.

A good understanding of the nature of the relationship between road transport and the economy is crucial for several reasons. First, because this relationship is supposed to help planners estimate the evolution of road freight transport demand over the years. And second, because knowing this relationship will help policy-makers adopt measures to promote sustainable growth since road traffic is responsible for a wide amount of externalities (European Union (2001), OECD (2002), OECD (2006)).

Up to now, the existing methodologies applied to explain road freight transport demand have been based on simulating the behaviour of multiple factors – including economic growth – influencing transport by using different models (e.g. Jong, Gunn. and Walker (2004) and Tavasszy (2006)). However, previous studies highlight the complexity of developing such type of models, partly because of the numerous factors determining the shipping of commodities in each country, and partly because of that lack of available data (Elaurant and Bates (2007)).

In the last few decades, there have been significant changes in the structure of the economy of many developed countries. The contribution of service-oriented sectors – such as financial services – to the national GDP has been growing in importance compared to, for instance, manufacturing activities. This trend has led to the “dematerialization of the economies”. That means the ‘reduction of material resources required per unit of GDP’ (Schleicher-Tappeser and Steen (1998) and even though it is well known that this process results in decoupling levels between transport and the economy, little research has been conducted about the impact of dematerialization on road freight transport trends.

This research intends to measure the impact that the structure of the economy has on road freight transport demand at the macro level – using a top-down approach – in a certain geographical area. For this purpose, we use an extended Input-Output (IO) model linking both the economic structure – structural relationships of production and consumption over time – and the road transport intensity in a certain country or region.

We have developed a methodology based on the definition of two scenarios that reflect a hypothetical evolution of the structure of the economy – towards a full dematerialization or a full materialization – and applied them to two case studies: Spain and the United Kingdom (UK). This methodology enables us to compare the results of the scenarios with the actual trends in terms of goods transport demand, and obtain conclusions from them.

The paper is structured as follows. In Section 2, right after the introduction, we identify the key variables explaining road freight transport trends from a macroeconomic standpoint. In Section 3 we define the methodological approach – the model and the scenarios. In Section 4 we provide an overview of the economic and transport characteristics of each case study. In Section 5 we show and describe the results obtained from the analysis. Finally, in Section 6, we highlight the main conclusions of this research.

2. Key drivers to explain road freight transport demand

It is well known that there exist a link between transport and the economy, but this relationship is complex because economic growth is not the only factor that determines freight transport trends. Effects such as technological innovations, changes in final demand or logistic improvements may also contribute to modify transport patterns (Alises et al. (2014)).

Road freight volumes are influenced by a wide range of factors that explain different trends across countries. Transport volumes depend on the levels of national economic output and consequently on the need to ship the commodities produced among different regions; and, on the other hand, on the organization of both the supply chains and transport systems.

In order to go further into the impacts that the two aforementioned factors could exert on transport volumes, in this section, we identify a set of quantitative variables that provide a direct knowledge on their evolution. Therefore, this analysis intends to identify the variables for defining our methodological approach. One of the specific contributions of this paper lies in defining the connection of such variables through an extended Input-Output model that will be explained in greater detail in the following section.

2.1. Using Input-Output Tables for transport modeling

The necessity of knowing the influence of changes in the production structure and economic patterns that may influence transport demand over time led to a new body of works in transport modelling. This is characterized by the development of transport IO models at urban and regional scale (see Ivanova (2014) for a deeper review).

The main reason for this trend is that several authors have pointed out the advantages of using these models in representing intersectorial interdependencies in production/consumption (Cascetta (2013)). This is crucial to define the interchange of goods – trade flows – and therefore the movement of goods in a region.

As previously said, research within this field has led to a number of operational land use-transportation models by incorporating spatial (or interregional) disaggregation data. Some examples are MEPLAN (Hunt and Echenique (1999)), TRANUS (de la Barra (1995)), PECAS (Hunt and Abraham (2003)) and RUBMIO (Kockelman et al. (2005)). These models combine IO data with additional information for trade and travel choices (travel costs, location of activities and population, mode choice models, etc.). That means that they usually need a big amount of available additional micro data to describe travel flows.

The IO approach has also been used to conduct several analysis at the macro level for planning processes and policy design in sectors such as the energy sector (see e.g. Lenzen and Foran (2001) and Alcántara and Padilla (2003)). It is noted that this type of studies has never been conducted for transportation field.

2.2. The role of road freight transport intensities in explaining transport trends

Freight transport volumes are also strongly influenced by the organization of supply chains. The transport system evolves and adapts progressively to respond to the requirements imposed by the emerging new organization of logistics systems. As Woxenius and Sjöstedt (2003) argued: logistics and transport systems are complementary.

Recent years have seen technological developments, increasing specialization, more sophisticated production processes, new distribution systems, and an ever greater concentration of manufacturing and storage (McKinnon and Woodburn, (1996)). All these factors have prompted changes in production and therefore in transport patterns, as supply chain organization influences aspects such as transport distances or modal split (OECD, (2006)). Therefore it is crucial to consider these factors as drivers of road freight volume. Previous literature found that all of these industrial, logistics and transportation systems changes can be understood through the so-called Road Freight Transport Intensity ratio (RFTI) (see e.g., McKinnon 2007, Kveiborg and Fosgerau (2007) or Piecyk and McKinnon (2010)) as a means of measuring “transport efficiency” in a certain country.

Brunel (2005) defined this ratio as the number of road freight transport units necessary to produce one dollar or one euro of GDP in a country. So, this could be measured in terms of tonne-kms per GDP, or even better veh-km per unit of GDP. However, authors such as Åhman (2004) argue that constructing sectional freight intensities based on sectors’ production – that is sectorial output – instead of GDP allows a deeper and more accurate understanding of transport growth in a certain economy.

RFTI – measured as veh-km/output [\$] – can be decomposed into several ratios whose values may change over time in terms of industrial, logistics and transportation systems restructuring (McKinnon 2007). These ratios help explain the evolution of transport trends over the years. These ratios are:

- Average value density: weight of goods of a certain economic branch divided by the monetary production value of this branch (tonne/\$). Changes in this ratio are explained by new product design techniques, manufacturing processes, and the current tendency to use lighter materials;
- Handling factor: referring to the number of times a product is lifted between the origin (production centre) and destination (consumption centre) in the supply chain for each type of commodity;

As Lehtonen pointed out in 2008, there are usually difficulties in accessing quality, reliable and complete data about both handling factors and value densities. In view of that, a new ratio can be defined: $\text{tonnes}_{\text{lifted}}/\text{Output} (\$)$, which is equal to the inverse value density times the handling factor. This ratio is named “freight intensity”. It is defined as the tonnes lifted divided by the value of the total production.

- Modal split: tonnes hauled by road compared to other modes;
- Average length of haul. This value depends on the location of industrial production, storage and consumption centres, and on the characteristic of the road networks;
- Load factor: the relation between the total tonnes carried and the loaded vehicles. It depends on both the mix of vehicles (with different sizes and capacities) and the lading factor of individual vehicles;
- Empty running: the percentage of total vehicle-kilometres which are run empty.

As equation (1) shows, by multiplying these ratios we obtain the RFTI in a certain country for sector i in a specific year, that is $RFTI_i$.

$$RFTI_i = \frac{veh-kms_{road,i}}{Output_i (\$)} \quad (1)$$

$$= \underbrace{\frac{tonnes_{lifted,i}}{Output_i (\$)}}_{\text{freight intensity}} \times \underbrace{\frac{tonnes_{lifted,road,i}}{tonnes_{lifted,i}}}_{\text{modal share}} \times \underbrace{\frac{tonne-kms_{road,i}}{tonnes_{lifted,road,i}}}_{\text{average length of haul}} \times \underbrace{\frac{veh-km_{loaded,i}}{ton-km_{road,i}}}_{\text{inverse of load factor}} \times \underbrace{\frac{veh-km_i}{veh-km_{loaded,i}}}_{\text{empty running}}$$

3. Methodological framework

One of the contributions of our paper consists of the definition of a new methodology that uses the information provided by the Input-Output tables to explain transport trends at the country level. This approach does not require as much information as some of the previously mentioned models do. However, by using aggregated information at the country level, it allows us to explain the global road freight transport trends in a certain country.

Figure 1 shows the methodological framework we use to connect economic and transportation variables – annual IO and RFTIs data – through an extended IO model. This framework will be used later on in this paper to simulate global road freight transport trends.

Fig. 1. Methodological framework scheme to estimate road freight transport demand.

The availability of IO tables for consecutive years in certain countries allows us to study the evolution of the factors previously mentioned and therefore to analyze how they influence road freight transport trends. On the other hand, countries are characterized by road freight transport intensities (RFTIs), which in their turn can be decomposed into several ratios. Annual RFTIs can be calculated as long as the information about national production and transport volumes is available. RFTIs can be explained in terms of other variables insofar as data such as modal split or length of haul is available at the national level. Below we explain our model in greater detail.

3.1. The extended Input-Output model

An Input-Output (IO) table consists of monetary transaction flows among the economic sectors of a country measured according to national accounting standards. This table shows inter-industry relationships within a certain economy – outputs from one sector (productive) that become an input to another sector (purchasing sector). The

basic IO model establishes a balance between total supply and total demand expressed by the equation of Leontief $x = (I - A)^{-1}f$, (Leontief (1936)) where x is the production vector – that is, the total output corresponding to the sectors of the economy, f is the final demand vector – including both domestic demand and exports – and $(I - A)^{-1}$ is the Leontief inverse matrix $[L]$ – which reflects the requirements of any industry supplied by the rest of sectors and by itself.

The IO approach can be extended by adding complementary information to the basic IO model to overcome the limitations of the information provided by the IO tables. Our IO model follows this approach by linking a vector of road freight transport intensities to a symmetric IO table sector by sector for the same year. This modification intends to show the structural relationship between economic activities and final road transport demand in a country.

In the following equations the economy is supposed to be structured in n economic sectors. Moreover, diagonalization and transposition will be respectively denoted by $^{\wedge}$ and $^{\prime}$.

T is as a vector ($n \times 1$) that contains the road freight transport demand sorted by commodity class. The road freight transport intensity vector (RFTI) can be defined according to the following equation:

$$RFTI = T'(\hat{x})^{-1} \quad (2)$$

Thus, we can obtain the road transport volume T in the following way:

$$T = \widehat{RFTI} x \quad (3)$$

Taking the value of x from the Leontief model, it leads to our extended IO model:

$$T = \widehat{RFTI} (I - A)^{-1}f \quad (4)$$

where the vector RFTI integrates transport flow data into the IO traditional analysis.

On the other hand, in an IO table the final demand can be calculated as the summation of the GDP vector – value added by sector – plus the vector containing the volumes of sectorial imports. So, the vector f can be expressed by other two vectors ($n \times 1$) that contain these components sorted by economic sector.

$$T = \widehat{RFTI} (I - A)^{-1}(GDP + Imp) = \widehat{RFTI} L(GDP + Imp) \quad (5)$$

The matrix $[L]$ and the vectors used – RFTI, GDP and Imp – in this transport model must reflect an identical disaggregation in the n activity branches considered. To that end the IO data and the transport data have to be homogenized in the same number of sectors when applying this formulation.

This model has been defined to explain road freight transport volume in terms of its own economic activity and some characteristics of the transport sector. That is to say, the model measures the volume of transport that is observed in each country as a consequence of national production and consumption, imports and exports of that country according to the IO tables. However, it is important to note that this model is not able to explain all transport volumes as it does not capture cross-country traffic – that is road traffic from one neighbouring country to another neighbouring country passing through the country of analysis.

3.2. Structural decomposition analysis

The structural decomposition analysis (SDA) has been widely used in the economic literature to identify the driving factors of changes over time. All variants of SDA are static comparative methods that examine time series of sector-level and/or country-level data. In essence, SDA formulates a variable, in our case road freight traffic T , in veh-km, as the sum or product of several explanatory variables. For the purpose of this research, these variables are (1) road freight transport intensities; (2) production linkages depending on the inter-sectorial relationships described by $[L]$; (3) sectorial GDP values; and (4) import volumes. A pair-wise comparison of changes at two specific periods of time can be undertaken by each of these explanatory variables.

Following this idea, the SDA technique may also allow us to evaluate the potential impact of a certain explanatory variable on the final output – road freight transport – by simulating alternative scenarios where this

explanatory variable evolves in a different way compared to the actual scenario. The SDA is conducted according to the equation (6) (Dietzenbacher and Los (1997)).

Through it, we can calculate the differences, in terms of aggregate road freight transport demand (ΔT^{0-1}), between the base year – expressed by superscript 0 – and each one of the subsequent years in the study period – expressed by superscript 1. This way, we can estimate the trend followed by the road freight transport demand in each country for the different hypothetical scenarios.

$$\begin{aligned} \Delta T^{0-1} = & \left(\frac{1}{2}\right) (\Delta \widehat{RFTI})^{0-1} [(L^0 (GDP^0 + Imp^0)) + (L^1 (GDP^1 + Imp^1))] \\ & + \left(\frac{1}{2}\right) [\widehat{RFTI}^0 (\Delta L)^{0-1} (GDP^1 + Imp^1) + \widehat{RFTI}^1 (\Delta L)^{0-1} (GDP^0 + Imp^0)] \\ & + \left(\frac{1}{2}\right) [(\widehat{RFTI}^0 L^0) + (\widehat{RFTI}^1 L^1)] (\Delta GDP)^{0-1} \\ & + \left(\frac{1}{2}\right) [(\widehat{RFTI}^0 L^0) + (\widehat{RFTI}^1 L^1)] (\Delta Imp)^{0-1} \end{aligned} \quad (6)$$

3.3. Economic scenarios

To measure the impact of the structure of the national economy on road freight transport we have defined two hypothetical scenarios where the economy evolves in the opposite way.

- Scenario 1 (*full materialization*). All the GDP growth in a certain country is absorbed by transport intensive sectors: According to this scenario we suppose that service-oriented branches of the GDP no longer grow after the base year. Consequently, intensive sectors experience a higher increase in their GDP compared to the actual scenario. The growth across intensive sectors is allocated according to their weight in the GDP of the base year.
- Scenario 2 (*full dematerialization*). All the GDP growth in a country is absorbed by service-oriented sectors: In this case we assume that the economic growth of each country results from service-oriented sectors. Consequently transport intensive sectors no longer grow after the base year.

For each of these scenarios we keep unchanged values (throughout all the study period) of the following variables: (1) the actual the global GDP growth, (2) the road freight transport intensity changes, and (3) the sectorial linkages and the volumes of imports values. The only variable we change is the structure of the GDP. Through these scenarios we seek to examine what would have happened to road volumes if GDP structure had evolved in a opposite way.

4. Empirical application: case studies and data

In order to apply the methodology defined in the previous section, we chose two case studies: the UK and Spain. We decided to select these countries for several reasons. First, different transport trends have been observed in the UK and Spain. In Spain road transport growth has closely followed GDP growth whereas in the UK high levels of decoupling have been reported. In the case of Spain we found that one of the main reasons explaining road freight transport trends was the impact of the construction sector, which contributed to curb decoupling by increasing the tonnes lifted across the country (it increased by more than 4% between 1999 and 2007, until the arrival of the economic crisis). In contrast, in the same period, most of the growth of the UK economy was produced by service-oriented sectors – with a share of 75.51% of the GDP in 2007. Therefore, we thought that it could be interesting to study in greater detail how road freight transport would behave in these two countries under similar restructuring processes of their economies. The second reason for selecting these countries is that there is enough homogeneous data available for the two of them – from both the macroeconomic and the transportation side. The third reason is the fact that cross-country transport, which is not captured by our methodology, in the UK and Spain is negligible compared to other type of transport.

As said before, our aim is to examine what would have been the macro trends of road freight transport demand in each country in case that the evolution of the economies described above had been different. In order to simulate the scenarios, we collected data from 1999 to 2011 from two sources: (1) annual data series of tonne-kms sorted by commodity group in each country and annual data series of veh-km obtained from EUROSTAT database, and (2) the annual IO tables for the same years compiled from World Input-Output Database (WIOD).

As we needed to integrate both transport and economic data in our methodology, we had to homogenize the information from the two databases. To that end, the original IO tables were aggregated into eight sectors representing the main areas of economic activity. This aggregation was made according to the commodity groups of the transport dataset. Transport data series from EUROSTAT changed its classification in 2007, so we have to homogenize the series across all the years of the period of study. Finally, we consider the following groups: (1) food, beverage and tobacco, (2) mining and construction, (3) textile sector, (4) energy: fuel and power products, (5) chemical products, (6) machinery and transport equipment, (7) manufacturing products and (8) services. The first seven sectors include the eighteen transport-intensive industries from the IO tables.

It is noted that the statistical data on transport by commodity class in a country provided by the EUROSTAT database only include transport operations made by domestic hauliers. This means that the foreign hauliers' activity is left out of the picture of this analysis. Nevertheless, in our two case studies this part of the transport volume only accounts for about 1% of the total road transport demand – between 0.6 and 0.8% in Spain and 0.9 and 1.1% in the UK according to EUROSTAT data series – so the distortion of the results is expected to be negligible.

Transport data is used to calculate the RFTIs that are subsequently introduced in our IO model. As the results of our simulation exercise strongly depend on the evolution of the RFTI, this ratio deserved to be analyzed in greater detail along with other ratios. This evolution is shown in Figure 2. Table 1 contains the mean values observed during the period of analysis. All these values are calculated on the basis of the EUROSTAT data series from 1999 to 2011.

Fig. 2. Evolution of global RFTI – $veh\text{-}km/output$ – and related ratios from 1999 to 2011 in Spain and the UK. Index 1999=100.

Looking at the graphs, several similarities and divergences between the behaviour of the key ratios in the two countries can be highlighted. The most notable case is the evolution of the amount of tonnes lifted per unit of monetary production. Whereas in the UK this ratio has been steadily decreasing ever since 1999, in Spain it significantly increased in 2002 and no lower values had been recorded after the base year until the arrival of the crisis. The mean value for this ratio is 68% higher in Spain than in the UK.

The growth of the service sector in the UK entailed fewer trips across the country. By contrast, the main reason for the trends observed in Spain was the expansion of the construction activity since mining and construction goods are low value materials and generate numerous as well as short-length trips. This fact may also explain the remarkable reduction of the average length of haul recorded in the country from 2001 and 2002.

The rest of the ratios have not changed substantially in Spain whereas in the UK both the load factor and empty running ratios have increased. Modal share has remained stable in both countries.

From this analysis we obtain that the RFTI has experienced a sharper decrease in the UK than in Spain throughout the period of study. From table 1 we see how, with the exception of the load factor, the rest of the ratios have got more efficient values in the UK than in Spain. This fact prompted a greater reduction of freight traffic volume in the UK.

Table 1. Mean values of RFTI and related key ratios in Spain and the UK in the period 1999–2011.

	tonnes/ output [millions US\$]	Modal share	Length of haul	Empty running	Load factor	RFTI (veh/ output [millios US\$]) ¹
Spain	861.4	94.7	122.5	27.4%	15.8	7011
UK	511.5	88.8	95.0	22.1%	9.2	6013

5. Results from the analysis of Scenarios

Scenarios 1 and 2 imply road freight transport volumes that delimit a traffic band for each country in which its road transport demand could have ranged depending on the type of economic growth experienced. Each scenario is associated to an elasticity [$\Delta \text{veh-km} / \text{veh-km} / \Delta \text{GDP} / \text{GDP}$] range that will be calculated later in this section.

In the case of Spain, after a small reduction of the global GDP from 1999 to 2001, the country experienced a high GDP growth until 2007. From 1999 to 2007 the GDP grew by 162%. Such an economic growth was accompanied by a notable increase of road freight transport demand – veh-kms grew by around 95% in this period. This was largely the result of an increase of 227% in the activity of the construction sector. At this period other sectors such as chemical industry (+123%) and services sectors (+144%) also reported significant growths.

Figure 3 shows the road freight transport trends obtained for the two scenarios simulated (S1 and S2) together with the actual trend, which remains within the grey band delimited by the two scenarios previously mentioned for each country. The growth of intensive-transport sectors in S1 implies a greater road freight transport increase. In the case of Spain, this trend is associated with elasticity values higher than one. On the other hand, for S2, when service GDP share is expanded, road freight transport is progressively detached from GDP, which leads to a clear decoupling trend with elasticity values around 0.1 in this country.

The graph for Spain draws our attention to the fact that road transport volume was above GDP in the three scenarios during the three first years of the study period. The reason explaining the similarity in all the scenarios is that in this period the GDP growth of all the economic sectors was rather small. Along with that fact, in this period road freight transport intensities in Spain grew a lot compared to the base year leading to positive road transport growths when global GDP decreased in all situations (see Fig. 2).

Fig. 3. Real GDP growth and road freight transport trends – $\Delta \text{veh-kms}$ (%) – under different economic scenarios in Spain (left) and in the United Kingdom (right) from 1999 to 2011.

Looking at the same analysis for the UK, it is seen that road freight growth began to separate from economic growth ever since 2003, accounting for traffic losses of nearly 15% after this year and elasticity values around -0.30. This trend was even more notable after 2007. During the economic crisis traffic reductions greater than 20% were observed compared to the base year. The dematerialization process was almost complete – the actual scenario is close to the S2 scenario. In addition to this fact, the road freight transport intensity in the UK has been declining over the years. These two trends have prompted road transport volume reductions with notable GDP growth ratios.

When comparing the results of the two case studies, one of the key outstanding issues is the notable difference in the relationship between the actual GDP growth and the trends obtained for veh-km in S1 for each country. In previous paragraphs we have already pointed out that in the case of Spain veh-km grew at a similar or even at

a higher rate than GDP when considering the hypothesis of the expansion of transport-intensive sectors. In the UK however, this situation for S1 is radically different since the road freight volume remains stable irrespective of the GDP growth.

Figure 4 summarizes the elasticity values obtained for the actual economic evolution, S1 (full materialization) and S2 (full dematerialization). Obviously, the actual elasticities are located within the range defined by the S1 and S2.

Fig. 4. Evolution of the elasticities of veh-km to GDP for the actual evolution of the economy and for scenarios S1 and S2 in the UK and Spain.

Moreover we measure the extent to which the level of dematerialization affects road freight volume for each case study by defining the dematerialization index (I_D) through equation (7). This index measures the situation of the actual scenario compared to Scenarios 1 and 2. Values close to 1 mean that the actual structure of the economy affects road transport volumes as if the economy was almost fully dematerialized.

$$I_D = \frac{E_{S1} - E_A}{E_{S1} - E_{S2}} \quad (7)$$

E_{S1} , E_{S2} and E_A are the averages of the elasticity values during the period of analysis of S1, S2 and the actual scenarios respectively. The value of the dematerialization index was 0.85 for the UK and 0.68 for Spain.

The comparison of the results obtained for the two countries shows significant differences between them. Firstly, the elasticity values are much lower in the UK than in Spain, and this is related to both a higher dematerialization index in this country and lower RFTI values. This finding allows us to conclude that dematerialization has been one of the key drivers to explain the decoupling trends in this the UK. Nevertheless, this index has also got a value of 0.68 in Spain. This fact confirms that, particularly in the last years of analysis, the loss of material intensity has also contributed to limit road freight transport growth in this country.

Figure 4 also shows that the elasticity range in the UK and Spain for Scenarios 1 and 2 is very different. Looking at the S2 (full dematerialization), this is much lower for the UK than for Spain, even reaching negative values. Figure 4 shows how the UK has attained an almost absolute decoupling level. The different elasticity values in the UK and Spain has been caused by differences in RFTIs between the two countries, as we have already analyzed in section 4 of this paper.

6. Conclusions

This research proves that Input-Output tables combined with transport information at the macro level may be a useful tool for explaining the evolution of road freight transport volume in a certain country. Despite the important progress achieved in the last few years regarding the use of IO tables to model freight transport at the regional and urban scale, IO tables also allow us to obtain interesting conclusions for policy makers by using top-down approaches such as the one we develop in this research, considering each time the validity of the IO data.

Economic restructuring processes in national economies play a significant role in explaining road freight transport volumes. The methodological framework developed in this paper has allowed us to demonstrate that, for the same global GDP growth, very different road transport volumes could be expected depending on the type of economic activity in a certain country. In this respect, different economic assumptions about the national

restructuring processes lead to the definition of a range where road freight transport could have fluctuated depending on the evolution of the structure of the economy.

In addition, this paper confirms that economic restructuring is not the only driver determining freight transport volume. Other non-economic variables – such as technological, logistic and modal aspects – influencing road freight transport intensities play also an essential role in explaining current and future transport trends.

Finally, for the two country case studies, we can say that the reasons behind the differences in road freight trends during the last few years were two. First, the UK has been a clear example of dematerialization of the economy while Spain was the opposite till the economic recession arrived in 2008. The great dependence of the Spanish economy on construction activities before 2008 entailed high transport volumes within this country. And, secondly, RFTI reductions became a reality in the UK few years earlier than in Spain. This fact helped promote decoupling in the UK while Spain hardly noticed it.

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3. COUPLING AND DECOUPLING FACTORS IN EUROPE

This chapter develops an EU-level cross-country comparison in order to identify the variables influencing European road freight trends in the last few decades. In addition, it aims at identifying the countries that have achieved significant decoupling and determining which factors have played the greatest role in decreasing road transport volume in each one.

The methodology implemented in this thesis through an extended Input-Output model is applied to go a step further in understanding both the key factors driving tonne-kms evolution in nine European countries at the macro level and the differences among them. This methodology connects the influencing variables on road transport: economic indexes —production, economic structure, intersectoral dependence imports or exports— and technological and logistic factors. The results found are contrasted with findings from previous research works.

Finally, this section provides an analysis about the consequences of decoupling trends on transport industry.

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Comparison of road freight transport trends in Europe. Coupling and decoupling factors from an Input–Output structural decomposition analysis

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ABSTRACT

Decoupling road freight transport from economic growth has been acknowledged by the European Union as a key means to improving sustainability. It is therefore important to identify both the coupling and decoupling drivers of road freight transport demand in order to determine possible factors that may contribute to reduce road transport in the future without curbing economic development. This research proposes an Input–Output (IO) structural decomposition analysis (SDA) to explain road freight transport in terms of a set of key factors that have strongly influenced road freight demand in recent decades in European countries—such as economic growth, economic structure and the evolution of road transport intensity (including improvements in both supply and transport systems). This methodological approach allows us to quantify and compare their contribution in different European countries to either increase or decrease road freight transport demand. The empirical basis for this analysis is a dataset of nine European countries which have IO tables and road transport data available from 2000 to 2007, comprising data on domestic production, imports and exports as well as tonne-kms for 11 types of commodity classes. The results show that, as a whole, aggregate road transport demand has grown—driven mainly by economic activity—but this growth has been strongly curbed in some countries by changes in road freight transport intensity and moderately by the dematerialization of the economy. International transport has been also proven to be a key factor driving road freight transport volumes. Moreover, the increased penetration of foreign operators in national haulage markets appears to have reinforced the final decoupling levels observed in some cases.

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1. Introduction

Transport is essential for economic development, but it is also responsible for a wide variety of externalities. Past trends indicate that for decades the European transport system has been moving away from sustainability hence causing environmental and social problems. Specifically, in the last decade transport has accounted for around a third of all final energy consumption in the European Union (EU) countries, and more than a fifth of greenhouse gas emissions. Moreover, road

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transport, the most energy and carbon intensive transportation mode, has become the dominant mode within Europe, ranking the highest share of inland freight in 2007 with nearly 80% in EU-27.

In this scenario there is an urgent need for actions aimed at reaching transport sustainability targets at both the national and European levels. The challenge, taken up by the EU, is to increase transport efficiency through the full internalisation of the negative side-effects of transport (European Commission, 2001a). To that end, the EU has promoted a number of policy measures to reduce road freight transport-related externalities (European Commission, 2003). One of the key tools for accomplishing this goal is to promote the decoupling of road transport growth from economic development (OECD, 2006).

Decoupling means to undo the traditional link between economic growth and road transport activity. This concept has been widely discussed in policy reports. It was the focus of the Standing Advisory Committee on Trunk Road Assessment (SACTRA) report in the United Kingdom in 1999, and has also been addressed in political documents such as the European White Papers entitled “European Transport Policy for 2020: Time to Decide” (European Commission, 2001b) and “Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system” (European Commission, 2011).

Within this context, over the last few decades decoupling has been partly taking place in some countries since they are making the transition to more service-oriented economies, and thus their economic growth has become progressively detached from road transport demand. Other sectors such as agriculture or mining demand more tonne-kms for their production processes than service sectors. As services have expanded their share of total GDP, this has led to higher economic growth than in the transport sector (Åhman, 2004).

Transport demand derives from economic activity, and the restructuring of the economy may lead to changes in the goods produced and moved, and in transport requirements. Specifically, freight activity is driven by complex and interlinked production processes and trade relationships. Recent years have seen globalisation trends, increasing specialisation, new production organisation systems such as ‘just-in-time’ distribution, and an ever greater concentration of manufacturing and storage (McKinnon and Woodburn, 1996). All these factors lead to changes in transport patterns, as supply chain organisation influences both transport distances and modal split (OECD, 2006).

As the evolution of all these variables may explain road freight transport trends and affect road sector in a different way in European countries, this research aims to meet four objectives:

- (1) The main goal is to identify the key factors driving road freight transport in recent decades in Europe. Through an IO structural decomposition analysis (SDA) we will break down road freight tonne-kms changes over time into the contributions of the key variables that have strongly influenced road freight transport demand in European countries. It will allow us to identify the factors that have played the greatest role in defining road transport trends. The decomposing method has been already applied in previous research works to analyse transport trends in some countries (see e.g. Kveiborg and Fosgerau, 2007 and Sorrell et al., 2012). Our research intends to combine this methodology with the IO model in order to incorporate the structure of the economy realistically in this type of analysis. It is noted that although IO techniques have been used in the past to develop road transport models (see e.g. Cascetta et al., 1996), neither this type of framework nor SDA analysis have ever been applied to explain and compare transport trends at the macro-level. In the light that SDA technique has already been used to explain energy consumption (e.g. Alcántara and Duarte, 2004, Wachsmann et al., 2009 and Lin and Polenske, 1995), and atmospheric pollution trends (e.g. Roca and Serrano, 2007), we consider that it may also be useful in this subject of transportation literature.
- (2) Provide an EU-level cross-country comparison of the results for different European Member States. We will look at similarities and differences between road freight transport trends in Europe and in the way different explanatory factors have impacted on their road freight transport. It will allow us to identify the countries that have achieved significant decoupling levels and the main reasons for this situation.
- (3) Confront our EU-level comparative results with findings from individual countries of previous research works dealing with decoupling. Most previous studies have analysed road transport trends only for a single country—often with a focus on the micro-level, whilst our paper aims to provide a homogenous macro-analysis for different European countries using the same type of data for all of them. Our results can be then compared with previous research works in order to show similarities or differences.
- (4) Analyse the impact of decoupling trends observed in some countries in the road transport industry of the EU countries in terms of profitability and organisation.

Accordingly, this paper is structured as follows. In Section 2 we describe the methodology and define the components explaining road freight transport demand. In Section 3 we develop our empirical application. In Subsection 3.1 we apply the methodology to measure the contributions of the several coupling and decoupling factors in nine EU countries. In Subsection 3.2 we develop a cross-country comparison pointing out the main similarities and divergences among these countries. We also compare our results with previous research works in this field. In addition, Subsection 3.3 provides a discussion of the effects of the decoupling trends in the road industry. Finally, Section 4 ends with some conclusions and highlights about the future research needs in this area. We also include two appendices: the first contains the mathematical expressions applied to obtain the structural decomposition equation; and the second, all the data resulting from the analysis by country and economic sector.

2. Methodological framework

The Input–Output (IO) table is based on national accounting. Its mathematical structure consists of monetary transaction flows among the economic sectors of a country. In the basic IO model (Leontief, 1936), interactions between both productive and purchasing sectors representing industries are characterised as an equilibrium between total supply and total demand, and can be expressed by the equilibrium equation of Leontief model $x = (I - A)^{-1}f$, where x represents the production vector—that is, the total output corresponding to all sectors of the economy, f is the final demand vector, and $(I - A)^{-1}$ is the Leontief inverse matrix $[L]$ —which reflects the requirements of any industry supplied by sectors.

Since the first IO works, some economic analyses based on an IO approach have added complementary information to the basic IO model structure to overcome the limitations of the information provided by the IO tables. Our methodological framework follows this approach in order to identify the key factors explaining road freight transport demand.

We assume that transport demand of a country depends on both production levels and productive structure, which is known through IO data. To define completely road freight transport demand we need in addition information about the volume of tonne-kms demanded by each economic sector in its production processes—that is the road freight transport intensities (RFTI) measured in tonne km/output.

Therefore, we add a vector to the conventional IO model containing road freight transport intensity by sector—from sector 1 to sector n —in each term: $RFTI = [RFTI_1, RFTI_2, \dots, RFTI_n]$.

RFTI values may vary across sectors and countries due to differences in certain aspects such as supply chain organisation and the evolution of road share compared to other modes (McKinnon, 2007). RFTI for each sector can be expressed through several ratios. These ratios are: (1) average value density—the ratio of the average weight of goods to the monetary production value (tonne/\$), which is influenced by new product design techniques, manufacturing processes, and the use of lighter materials; (2) handling factor—determining how the goods produced and imported into the economy are translated into the total tonnes lifted by all transport modes depending upon the number of nodes existing in the supply chains between production and final consumption; (3) modal split—in this case we use the data for tonnes hauled by road; and (4) average length of haul—which depends on the location of industrial production and storage centres, on the configuration of road networks and on the vehicle routing.

As Eq. (1) shows, by multiplying these values we can obtain the RFTI in a certain country for a certain sector i , that is $RFTI_i$. These values may vary over time as a result of either structural or logistical changes, and thus for an accurate analysis of road transport trends, RFTI should be estimated annually for each economic sector and country.

$$RFTI_i = \frac{\text{tonnes} - \text{km}_{\text{road},i}}{\text{Output } [\$]} = \underbrace{\frac{\text{tonnes}_{\text{produced},i}}{\text{Output}_i [\$]}}_{\text{inverse of value density}} \times \underbrace{\frac{\text{tonnes}_{\text{lifted},i}}{\text{tonnes}_{\text{produced},i}}}_{\text{handling factor}} \times \underbrace{\frac{\text{tonnes}_{\text{lifted,road},i}}{\text{tonnes}_{\text{lifted},i}}}_{\text{modal share}} \times \underbrace{\frac{\text{tonne} - \text{kms}_{\text{road},i}}{\text{tonnes}_{\text{lifted,road},i}}}_{\text{average length of haul}} \quad (1)$$

Therefore, using the equilibrium matrix equation of the Leontief model $x = (I - A)^{-1}f$ together with the RFTI vector we define the aggregate road transport demand T according to the following equation Eq. (2). Through it we connect economic indexes—production, economic structure, inter-sector dependences, imports and exports—and technological and logistical factors—such as modal split, supply chain structures and road networks.

$$T = \widehat{RFTI}(I - A)^{-1}f = \widehat{RFTI}[\bar{s}\Sigma GDP + \text{Imp}] \quad (2)$$

By using an annual IO table, the final demand vector f can be expressed by adding the sectorial GDP vector and the vector of sectorial import volumes. We have used that mathematical relationship to express Eq. (2) and also a vector $\bar{s}$ that expresses the participation of the sector GDP in the aggregate national GDP, and thus we have included the global annual value of each country's GDP.

The matrix $[L]$ and all the vectors used—RFTI, $\bar{s}$ and Imp—in this transport model must reflect an identical disaggregation in the n activity branches considered.

Thus by applying the SDA technique we are able to break down the aggregate changes in road freight transport demand in a particular economy into the contributions of five main factors, namely: (1) changes in road transport intensities; (2) variation in production linkages depending on the inter-sector relationships described by $[L]$; (3) changes in GDP structure, that is to say, the sector share of total GDP; (4) global growth or decrease in GDP; and (5) changes in import volumes. This analysis enables us to quantify the contributions of these five variables to the evolution of road freight transport volumes in a specific country from the base year—expressed by the subscript 0—to each one of the following years in the study period—subscript 1. That is to say, we explain $\Delta T^{0-1} = T^1 - T^0$ —measured in tonne-kms, through the following Eq. (3), resulted from applying the theory proposed by Dietzenbacher and Los (1997) to Eq. (2). A more complete explanation of the process used to obtain this equation is described in Appendix A.

$$\begin{aligned}
\Delta T^{0-1} = & \underbrace{\left(\frac{1}{2} \right) \left(\widehat{RFTI} \right)^{0-1} \left[L^0 (\bar{s}^0 \Sigma GDP^0 + Imp^0) + L^1 (\bar{s}^1 \Sigma GDP^1 + Imp^1) \right]}_{\text{Road freight transport intensity change effect}} \\
& + \underbrace{\left(\frac{1}{2} \right) \left[\widehat{RFTI}^0 (\Delta L)^{0-1} (\bar{s}^1 \Sigma GDP^1 + Imp^1) + \widehat{RFTI}^1 (\Delta L)^{0-1} (\bar{s}^0 \Sigma GDP^0 + Imp^0) \right]}_{\text{Production linkages effect}} \\
& + \underbrace{\left(\frac{1}{2} \right) \left[\widehat{RFTI}^0 L^0 (\Delta \bar{s})^{0-1} \Sigma GDP^1 + \widehat{RFTI}^1 L^1 (\Delta \bar{s})^{0-1} \Sigma GDP^0 \right]}_{\text{GDP structure change effect}} \\
& + \underbrace{\left(\frac{1}{2} \right) \left[\left(\widehat{RFTI}^0 L^0 \bar{s}^0 \right) + \left(\widehat{RFTI}^1 L^1 \bar{s}^1 \right) \right] (\Delta \Sigma GDP)^{0-1}}_{\text{GDP growth/decrease effect}} \\
& + \underbrace{\left(\frac{1}{2} \right) \left[\left(\widehat{RFTI}^0 L^0 \right) + \left(\widehat{RFTI}^1 L^1 \right) \right] (\Delta Imp)^{0-1}}_{\text{Imports volume change effect}}
\end{aligned} \tag{3}$$

Therefore the difference between the aggregate road freight transport demand in a country over two years is split into five components— C^1 , C^2 , C^3 , C^4 and C^5 —which are each individually contained in separated lines of Eq. (3). Each one of them is a vector that contains the sectorial contributions to vary total road freight transport depending on the evolution of the variables mentioned above.

The first term, C^1 , captures how much of the increase or decrease in tonne-kms can be attributed to changes in RFTI values in the economic sectors. The second component, C^2 , is the “production linkages effect”, and shows the effect on the aggregate road freight transport volume of the different use of inputs in the production processes between year 0 and 1. This effect is caused by technological changes in the economy. C^3 reflects how changes in the GDP structure modify road freight transport demand—we call it the “GDP structure effect”; and finally C^4 and C^5 quantify the contributions of GDP growth and the changes in import volumes to the increase/decrease in aggregate tonne-kms respectively in a country.

We should point out that our methodological approach can explain the evolution of road freight transport demand derived from countries’ economic activity as measured by national IO tables. Our model cannot explain far-reaching shifts in traffic in countries with substantial amounts of cross-country traffic, only the proportion of national and international transport in these countries.

3. Empirical application. SDA of freight transport demand of European Union countries

In this section we implement the methodological framework defined above in nine countries of the European Union—Germany, Spain, France, the United Kingdom (UK), Italy, Finland, Sweden, Portugal and Ireland—using data from 2000 to 2007. We considered these countries to be representative for several reasons: first, among them there are some of the largest in Europe; second, they show notable divergences in road transport trends; and third, some of them have been the target-countries of previous decoupling studies, which allows us to compare and confront our results in response to the third objective of this research. Other large European countries were not considered as there is no available data to conduct the analysis described above in the study period.

3.1. Data sources

The information on road freight transport demand—data series of tonne-kms sorted by commodity group in each country—was obtained from Eurostat. Economic data were collected from the Input–Output (IO) tables compiled by the World Input–Output Database (WIOD). This dataset provides the IO tables at current prices in US\$ according to the national accounts.

The reason for using data until 2007 is twofold: first, the lack of complete information related to sector transport demand by commodity after this year; and second, the intention to avoid the impact of the economic downturn in Europe which might distort the final results.

To homogenise the economic and transport data in an identical disaggregate level, we aggregated the original database—both the transportation statistics by commodity class and the IO table—into a set of groups representing the main areas of economic activity. To that end, we checked the list of commodity groups included in the transport dataset that can be assigned to the output of either an industry or a group of industries of the IO tables. On the basis of this analysis, we aggregated all the economic data of the annual IO tables—intermediate sales and purchases, GDP and imports—of all the industries linked to the tonnes and tonne-kms series for different types of goods. Due to the fact that the classification of the two types of data is very different, in the end we decided to work with eleven sectors: (1) food, beverage and tobacco, (2) mining, (3) textile sector, (4) wood industry, (5) paper, printing and publishing, (6) energy: fuel and power products; (7) chemicals, (8) machinery and transport equipment, (9) manufacturing, (10) construction, and (11) services.

Table 1

Variation in road freight transport demand—in % of tonne-kms—by commodity group and real GDP growth—% of real GDP in each country—from 2000 to 2007.

Sectors	Countries								
	DE	ES	FI	FR	IE	IT	PT	SE	UK
<i>Δ tonne-kms</i>									
Food, beverage and tobacco	+27	+73	−6	+6	+40	−10	+72	+17	−23
Mining	+8	+101	−4	+15	+102	−1	+47	+22	+5
Textile sector	+33	+81	−18	−17	+37	−6	+62	−8	−25
Wood industry	+25	−22	−24	−5	+57	−18	+50	+13	−27
Papers & Printing	+48	+90	−23	−15	+500	−3	+18	−3	+30
Energy goods	−7	+32	+24	+14	+22	+7	+58	−7	−34
Chemical products	+36	+50	−6	−19	+17	−10	+120	−14	−27
Machinery & Transports	+42	+107	+37	−17	+135	−22	+84	+4	−21
Manufacturing	+24	+25	+39	−8	−33	−26	+94	+46	−21
Construction products	−10	+116	+8	+28	+57	+12	+49	+12	−4
Service products	+44	+46	±0	+26	+49	+16	+167	+30	−12
Total	+24	+74	−7	+8	+54	−3	+73	+15	−17
<i>Δ real GDP</i>	+10	+26	+25	+13	+41	+9	+8	+23	+23

Countries: (DE) Germany, (ES) Spain, (FI) Finland, (FR) France, (IE) Ireland, (IT) Italy, (PT) Portugal, (SE) Sweden, (UK) United Kingdom.

Table 1 shows the total percentage of increase/decrease of road transport demand in tonne-kms by commodity group, and the variation in aggregate road transport demand for each country throughout the study period. In this research we explain these changes through the effects described above. Different patterns can be identified at a glance. In most countries the aggregate road transport volume increased, albeit unevenly, with a very wide variability range across this group of countries. However, in other countries such as Finland, Italy and the UK lower road transport volumes were registered in 2007 compared to 2000, even with real GDP growing during this period—as we also see in the table. The question that arises now is what factors really explain these differences and how we can characterise them.

3.2. Key factors driving road freight transport trends in Europe

In order to achieve the first objective of this paper, we apply Eq. (3). In that way, we calculate the impact of the evolution of road transport intensity, production structure, GDP structure, growth in GDP and import volumes on the annual aggregate road freight transport demand for each commodity class. These contributions by sector are shown in Appendix B in the % of tonne-kms that road transport volume would increase/decrease due to the isolated effect produced by the change in each sectorial variable. Moreover, by aggregating all sector contributions for all the five components we obtain the total variation of road freight transport explained by each effect, and finally by aggregating these five contributions we obtain the global change in road freight transport between the base year 2000 and the other years in the study period.

The sectorial results reveal the most relevant sectors fuelling road transport demand trends by adding or declining tonne-kms in each country. Overall the road transport volumes in Europe are very sensitive to the behaviour of the food, beverage and tobacco sector. It is the largest sector in terms of tonne-kms (Eurostat, 2013), largely due to the fact that it is linked to long-distance transport, and thus has higher road transport intensity than others. In most countries the reduction of RFTI for the food, beverage and tobacco sectors contributed substantially to the decline in road freight transport demand. This sector has important linkages with other sectors; for instance, it sells inputs to hotels and catering services.

Another sector worth highlighting for its positive contribution to freight transport demand in some countries is the mining sector. This sector is partly driven by the construction industry, which from 2000 to 2007 – before the onset of the recession – grew significantly in countries such as Spain, Portugal and Sweden. However, despite these common patterns, the main conclusion to be drawn from the results is that there are major asymmetries in the way industries contribute to increasing/decreasing road freight transport volumes across the European countries in the study. This trend is largely dependent on each sector's growth by country, the weight of each sector in the economy, the evolution of sector linkages, and the performance of the supply chain.

As indicated above, the final contribution of each factor explaining road transport demand is obtained as the summation of each sector's contributions. Fig. 1 below shows the aggregate results per country between 2000 and 2007. For each one of the countries analysed, each coloured bar on the graphs within this figure displays the total tonne-kms that final transport would have increased or decreased (in %) in relation to the base year (2000) due to the individual effect of each one of the contributing factors. The summation of all the five contributions leads to the actual variation of road transport in each country represented by the discontinuous red line.

Both GDP and imports contributed to increasing tonne-kms in all countries. As a consequence of this trend, in Spain, Portugal and Ireland road freight transport volumes steadily increased at rates closely matching economic growth, whereas in other countries such as Finland and Italy, road transport remained stable or even declined under economic growth scenarios. According to the figure, this effect is mostly explained by changes in RFTI, with moderate contributions from sector production linkages and GDP structure effects.

Fig. 1. Contribution of all effects to changes in road freight transport from 2000 to 2007.

The results reveal that all these countries evolved towards economies led largely by sectors with relatively low transport intensities, and most of them (excluding Portugal) seem to have incorporated structural, procedural and logistical changes into their supply chains that caused a sustained decrease in global road freight transport intensity, as we will explain later. The most significant decoupling effect took place in the UK, where road transport volume fell by 17% from 2000 to 2007 while its GDP increased by 23% in the same period. This trend was already detected for the UK between 1993 and 2003 since the ratio of inland tonne-kms to GDP in the UK declined by 12.7% during this period while it increased by 8.8% across the EU15 as a whole (Department for Transport, 2005; Eurostat, 2005).

According to Fig. 1, the evolution of RFTI has been the most important factor contributing to road freight transport decoupling from GDP growth. However, as road freight transport intensities depend on several ratios (value densities, handling factors, modal split and haulage distances), identifying the reasons behind the variation of the RFTI ratio for each country turns out to be a complicated issue. Piecyk and McKinnon (2010) noted that there exists a complex inter-relationship between the ratios previously defined and six factors that influence them: product related factors, structural factors, commercial factors, operational factors, functional factors and external factors.

On the one hand, different product-related factors (i.e. products characteristics) affect the nature of transport operations. Structural factors in each region determine the organisation of logistics systems and the configuration of supply chains in terms of number, location and capacity of factories and warehouses, clearly influencing the final values of handling factors or haulage distances. Commercial factors—sourcing and distribution strategies, functional factors—management of transport resources, and operational factors—affecting the scheduling of product flow—determine the way that goods are ultimately delivered. All these factors influence the selection of the transportation modes, the handling systems, the routing of deliveries, etc. Finally, external factors such as government regulations or tax policies may also contribute to vary some of these key ratios.

Table 2 provides a synthetic presentation of some examples of factors—grouped into the aforementioned categories—affecting the key ratios that determine RFTI. The direction of the arrows show whether each factor increases or decrease each one of the four ratios defined.

Multiple factors play a role to explain RFTI, which in their turn would determine road freight demand trends. However, getting to know in detail the impact of each one of the factors defined above through a macro approach is not feasible. Therefore, analysing the impact of different production and logistics trends and measures would require new empirical research at the micro level for each case study. Section 3.3 provides a more detailed explanation of the different patterns followed in some of the analysed countries based on previous research works.

On the other hand, from Fig. 1, we have also noticed that the growth in tonne-kms in the EU countries can be partly attributed to the increasing flow of imported goods across Europe. Although the contribution of the expansion of exports has not

Table 2
Factors affecting the key ratios explaining road freight transport intensities.

	Value density	Handling factor	Modal split	Length of haul
<i>Product-related factors</i>				
Increasing quality of goods	↑			
Miniaturization of products	↑			
Access to cheaper raw materials	↓	↓ (1) ^a		↓ (1) ^a
Use of lighter materials	↑			
Adding more stages in the production chain	?	↑	↑	
<i>Structural factors</i>				
Spatial concentration of production and inventory		↓		↑
Development of urban consolidation centres		↓		↓
Relocation of production centres and warehouses			↓ (1) ^b	↓ (1)
Concentration of international trade on hub ports		↓	↓	↑
<i>Commercial factors</i>				
Improving productivity	↓		↓?	
Increases in the volumes of goods and services traded online		↑	↑	
<i>Operational factors</i>				
Application of JIT—Just In Time—principle		↑	↑	
Increase in nominated day deliverables		↑	↑	
<i>Functional factors</i>				
Use of vehicle routing and scheduling systems				↓
<i>External factors</i>				
Fuel prices			↓	
Introduction of road charging			↓	
Investment in alternative transport modes/intermodality			↓	

Source: Own elaboration partly based on Lehtonen (2008) and partly on Piecyk and McKinnon (2010).

^a Cheaper raw materials may be located faster/closer than traditional raw materials, and using them may involve more/less and longer/shorter intermediate journeys as it may change production processes.

^b Locating production and warehouses close to ports and railway terminals promotes the construction of intermodal freight terminals bringing about competitive benefits to alternative modes of transport. Otherwise, road share would increase.

Fig. 2. Goods moved (in tonne-kms) and real GDP evolution in the UK. (Index 2000 = 100).

Table 3

Contribution of foreign transport activity to road freight transport (% of tonne-kms) between 2000 and 2007.

	DE (%)	ES (%)	FI (%)	FR (%)	IE (%)	IT (%)	PT (%)	SE (%)	UK (%)
Δ tonne-kms	+10	−1	+3	+18	+6	+13	−8	+10	+10

Source: Own estimation based on Eurostat dataset “International annual road freight transport by country of loading and unloading with breakdown by reporting country (1000 t, Mio Tkm)” http://ec.europa.eu/eurostat/web/products-datasets/-/road_go_ia_rc.

been directly quantified, due to the fact that we have adopted an income approach, exports changes are implicitly incorporated within GDP growth so its impact on increased volumes of tonne-kms is actually accounted for.

The creation of a single market for road freight transport in 1993 led to both the removal of controls at the borders and the liberalisation of international road haulage. This fact caused different effects. Nationally-based manufacturing and national distribution systems were gradually replaced by pan-European networks leading to larger international transport volumes. In some cases, the whole continent was served by a single factory or warehouse (Bayliss and Millington, 1995). The liberalisation also accelerated market entry and increased competition between national and foreign transport companies across EU countries.

McKinnon (2007) pointed out that the share of foreign-registered trucks entering the UK had been steadily growing until 2004. He stated that this trend was partly responsible for the decoupling levels measured in this country since transport surveys and tonne-kms statistics do not usually cover the foreign-registered vehicle activity in a country. This is the case of the EUROSTAT data that we are using in this research. Foreign-registered vehicle activity in a country—cabotage and international transport (both dispatch and receipt) carried by foreign-registered vehicles—is excluded from this type of data series.

Fig. 2 shows for the UK the amount of tonne-kms moved only by British hauliers and by both British and foreign-registered HGVs (estimated based on the Department for Transport statistics) compared to real GDP growth. The observed trends support McKinnon’s idea that the non-inclusion of international foreign transport data may reinforce the decoupling trends calculated through transport statistics.

As a consequence of this evidence, it seems necessary to take into account the impact of foreign hauliers. In order to provide insight into the impact of this factor in the coupling/decoupling trends in all the countries analysed, we have incorporated the increase/decrease of tonne-kms caused by the evolution of the level of foreign hauliers’ activity between 2000 and 2007 (see Table 3). We have conducted the estimates based on the Eurostat dataset “International annual road freight transport by country of loading and unloading with breakdown by reporting country (1000 t, Mio Tkm)”.

According to the figures shown in Table 3, we can conclude that the penetration of foreign operators in some countries—such as France, Italy, Sweden and the UK—has significantly contributed to overestimate their decoupling trends when using EUROSTAT data. In other countries, like Spain or Finland, the effect has been almost negligible. In Portugal the balance was negative so its decoupling trends were underestimated, which reinforced the Portuguese coupling trend.

3.3. Analysis of similarities and divergences through a cross-country comparison: confrontation with previous research works

It is widely accepted that there has traditionally been a historic correlation in most countries between gross domestic product (GDP) and road freight transport demand with both following similar trends (see e.g. Tapio, 2005 and Stead, 2001). However, some authors have already pointed out that this appears to have changed over the last few years since the emergence of new decoupling trends in a number of countries—partly due to increasing share of services within GDP and partly to efficient changes in road transport intensity—(Alises et al., 2014). In some countries, transport has continuously grown, but at a lower rate than GDP growth, in a process that can be defined as weak decoupling—that is, the link between transport and the economy has been weakened. In other countries, transport growth has been negative while economic

growth has been positive, which could be defined as strong or absolute decoupling—the link has been broken—(Ballingall et al., 2003). Numerous works have focused on these trends pointing out that decoupling levels were more likely to appear in ‘peripheral’ EU countries (e.g. Tapio, 2005 and McKinnon, 2007) due to the increasing freight transport in centrally located countries.

In 2005, Tapio cited a weak relative decoupling between freight traffic (and also for passengers) and GDP during the 1990s in five countries: Finland, Sweden, the UK, Ireland and Luxembourg. By contrast, in the Netherlands and Portugal, he identified an expansive negative decoupling while transport volumes grew at higher rates than GDP. In all the other countries of EU-15, GDP decreased during that decade while transport continued to grow. Tapio emphasised the exceptionally high elasticity values observed in Germany in that period. According to Leonardi, some drivers of that trend were the globalisation and the opening of Eastern European markets. This growth was mostly absorbed by the road mode due to the low competitiveness of German freight rail (Leonardi, 2006).

In view of our results, we can provide a classification of our sample of countries based on the degrees of coupling and decoupling of transport volume growth from economic growth given by Tapio in the above mentioned study (see Fig. 3). That analysis, together with the other contents of this subsection, is focused on the second and third objectives of this paper.

We observe that there are clear differences between the levels of decoupling experienced by the studied countries over the past few years. Countries like the UK and Finland, where Tapio noted a situation of weak decoupling in the 90s, have already achieved a strong decoupling level. Other countries—Portugal, Spain and Germany—still remain in an expansive negative decoupling state. It is noted that Ireland is very close to achieve the next region of expansive coupling (that means, $\Delta \text{tonne-km} / \Delta \text{GDP}$ is near to the range 0.8–1.2). Finally we can see how Sweden and France have evolved from an expansive negative decoupling to a weak decoupling level.

It is worth reminding that this classification was made based on the EUROSTAT data used in this research. As we noted above, these data do not include the effect of the increase of foreign-hauliers activity in some countries. Fig. 4 incorporates the effect of foreign hauliers and, as a consequence, changes the region where some countries fall compared to Fig. 3.

The most relevant changes are the following ones: France moves away from a weak decoupling situation to an expansive negative decoupling; Italy is ultimately classified as a country with expansive coupling trends instead of the strong decoupling recorded previously; and finally Sweden falls into the expansive decoupling region instead of into the weak decoupling one.

Once we have classified all the countries, on the basis of the results obtained from the application of our IO model, we can clearly identify groups of countries where some significant factors have strongly promoted decoupling. In order to synthesise all the information, we conducted a cross-country comparison focused on the three first aggregate contributions represented in Fig. 1, which do not depend on national economic growth but on the evolution of structural, production and logistical features namely: road transport intensity evolution (C^1), production linkages effect (C^2) and GDP structure effect (C^3). As noted before, these may be influenced in one way or another by structural and good supply companies decisions and strategies, as well as by some policy measures.

We use the value of the total contributions of these factors for each country (shown in Appendix B and graphically represented in Fig. 1). By contrasting them with the average values, we can classify the countries (Table 4) according to their

Fig. 3. Level of decoupling of freight transport volume from GDP in EU countries from 2000 to 2007 according to Eurostat statistics.

Fig. 4. Level of decoupling of freight transport volume from GDP in EU countries from 2000 to 2007 taken into account the transport volume of foreign haulers in each country.

behaviour compared to the average contribution of each factor. In countries above the average, these factors contribute more to increasing road freight transport and less to decoupling.

Looking at this table, we can easily identify the countries that contribute either positively or negatively to decoupling in Europe. Finland, Italy and the UK are the countries in which the effect of RFTI evolution was most effective in reducing road freight transport demand (it is fulfilled that $C^1 < C^1_{mean}$), and these countries are the three ones that have achieved high decoupling levels (see Fig. 3). In contrast, according to the first column of the table, the RFTI evolution in Portugal had an almost negligible effect on reducing road freight transport demand. This last finding is also seen in Fig. 1, which shows that this effect even led to an increase in road freight transport in many of the years in the study period compared to the base year 2000. In both Germany and in Spain, this effect also seems to have had no major impact compared to the rest of the countries.

It is clear that after 2004, RFTI clearly contributed to reduce road transport in the UK (see Fig. 1). In this country Lehtonen (2006) identified clear decoupling trends during 1990s and provided a list of reasons for this situation by developing a decomposition analysis of road freight transport into different factors. He found that after this year the shortening of the average length of haul began to influence decoupling. During previous decades, the increase of the average haulage distances was identified as the main factor contributing to increase road transport (NEI, 1997), partly due to the concentration of the economic activity. However, the new trends pointed out by Lehtonen suggested that such long-established concentration of production and inventory was beginning to weaken. It could be also caused partly by the outsourcing of delivery processes to large companies managing warehouses in many areas. In this respect, McKinnon (2007) pointed out that the average length of haul for road freight in the UK between 1998 and 2003 actually declined by an average of 0.1% per year, in contrast to the 2–2.5% annual increase over the previous twenty years. Particularly, this variable dropped by 5.2% in 2004.

The UK has been a targeted case study in this type of research works due to its pronounced decoupling trend. In the research by McKinnon (2007), already quoted above, the author listed different possible reasons for the trends observed in this country between 1997 and 2004. In addition to the reduction of the average length of haul, he noted that the increas-

Table 4

Classification by countries on the basis of their contributions to road transport demand.

$C^1 > C^1_{mean}$ ^a	$C^2 > C^2_{mean}$ ^b	$C^3 > C^3_{mean}$ ^c
Portugal, Spain, Germany	Ireland, Finland, Spain, Sweden, Italy	Sweden, Germany, Italy, Finland
$C^1 < C^1_{mean}$	$C^2 < C^2_{mean}$	$C^3 < C^3_{mean}$
Sweden, France, Ireland, United Kingdom, Italy, Finland	France, Germany, United Kingdom, Portugal	France, Portugal, Spain, Ireland, United Kingdom

^a C^1 is the contribution of changes in road freight transport intensities.

^b C^2 is the contribution of restructuring in sector production linkages.

^c C^3 is the contribution of GDP structure changes.

ing geographical coverage by domestic supply chains, the increase of road freight costs and the decline in road's share of the freight market were some of the most significant reasons promoting decoupling in this country during that period.

Looking at other works analysing other of our case studies like Finland, we find that Liimatainen and Pöllänen (2013) pointed out that, in contrast with what happened in the UK, haulage distances tended to increase in this country while the growth of value density in all sectors appeared to be the main reason for the decreasing road freight transport intensity between 1995 and 2010. This trend is similar to the one found in Sweden between 1990 and 2008 by Eng-Larsson et al. (2012), which may partly explain our results regarding the negative contribution of RFTI to Swedish road freight transport. The authors noted that this trend could be explained by the shift to a more knowledge-based manufacturing industry as well as a general transformation towards more service-oriented economies. As seen in previous section (see Table 2), these trends fostering decoupling value densities could have been also increased by processes such as the miniaturization of products, the increasing quality of goods or the trend to use lighter materials.

Liimatainen and Pöllänen also highlighted that, in Finland, modal split remained stable during their period of study since the road's share remained between 88.6% and 90.0%. According to this fact, they concluded that the modal split had virtually no effect on transport intensity, and therefore on road freight transport demand. By contrast, in the case of Sweden, Eng-Larsson et al. (2012) found that the experienced changes in modal split had contributed to increase road transport.

It is clear that the shift away from road to other more environment-friendly modes has been one of the main transport policy challenges over the last decades since it has been understood as a key factor for promoting decoupling, and therefore sustainable transportation. Overall, the likely potential of modal shift depends on the application of some measures—spatial transformations, the investment in the development of new or improved road and non-road infrastructure and the improvement of intermodal networks. It also varies according to the characteristics and attractiveness of the different transport modes—travel costs or level of emissions. Despite the strong concern of the EU about the road transport use and the regular development of environmental policies towards the reduction of the road share, road transport still domains in Europe. According to EEA (2011), this can be explained by the higher ability of road transport, compared to other modes, to take advantage of the elimination of trade barriers, along with the fact that the liberalisation process in the road sector has been faster and more effective than in other modes such as inland waterways and rail. In addition, the road transport mode is more flexible than the rest of inland modes, so it is more capable to adapt to new emerging delivery systems such as 'just in time'. Furthermore, it is worth noting that many of the destinations—production and consumption centres—can only be reached by road and combined transport is only practised to a limited extent. These intrinsic advantages of road transport in the emerging transport markets together with other barriers such as the high investments needed for improving rail and waterway networks lead in some countries to the need for very large efforts to effectively reduce the road share (Essen et al., 2009).

Within this context, looking at the modal trends of all the countries selected, we clearly see that road transport has been the predominant mode in all the countries, and its share in terms of tonnes, as is included in our definition of RFTIs—has remained more or less stable in all of them as it has occurred in most of the European countries (see Fig. 5). Only in Italy and Finland there seems to be a trend towards reducing the share of the road in the last two years of our analysis. However, even though it is true that railways have not achieved to increase road share substantially in the period of analysis, it is also true that this increase would have likely been much higher if no measure to revitalise railways had been adopted in Europe.

On the other hand, we showed earlier that the other two components taken into account to classify our sample of countries in Table 2— C^2 and C^3 —did not have such a significant impact as the evolution of RFTI (this is C^1) on the reduction of tonne-kms. This result is consistent with one of the conclusions by Niederl et al. (2003), who noted that freight transport volumes can be influenced more by the restructuring of the 'production-consumption chain' than by variations in the material flows throughout the economy. However, if we look at the results we noted that the evolution of the GDP structure positively contributed to decreasing road freight transport volumes over the study period in all countries. Considerable decreasing contributions can be noted in the UK, Ireland and Spain due to this effect ($C^3 < C^3_{\text{mean}}$).

In most developed countries there has been a shift towards service-oriented rather than manufacture-oriented economies. Here we can highlight the UK, where the share of the service sector of the economy began to rise in the mid-1990s, until reaching a peak of 70% in 2007. In this country, Lehtonen (2006) had already found a declining share of GDP of manufacturing about 27% between 1989 and 2004 leading to less transport demand. However, Mckinnon noted that this trend actually had a minor effect on decoupling compared to other factors.

Fig. 5. Road's share in tonnes between 2000 and 2007. Source: Eurostat data.

Table 5

Road transport sector evolution from 2000 to 2004.

	Number of companies	Value added at factor cost	Gross operating surplus	Number of persons employed
Germany	+6%	+11%	+9%	+17%
Ireland	+33% ^a	+11% ^a	(–)	+27% ^a
Spain	+6%	+88%	+69%	+38%
France	–4% ^b	+24% ^b	–4% ^b	+14% ^b
Italy	–17%	+27%	–5%	+12%
Portugal	+100%	+61%	+45%	+46%
Finland	–5%	+38%	+14%	+14%
Sweden	+4%	+26%	+32%	+18%
United Kingdom	–8%	+11%	+15%	–10%

(–) Non available data.

Source: Own calculations based on Eurostat dataset “Annual detailed enterprise statistics on services (NACE Rev. 1.1 H-K)” http://ec.europa.eu/eurostat/web/products-datasets/-/sbs_na_1a_se.^a Data increases from 2000 to 2004.^b Data increases from 2001 to 2007.

In contrast, this tendency was not noted in countries such as Sweden and Germany (where it is fulfilled that $C^3 > C^3_{\text{mean}}$), since transport intensive sectors such as mining and machinery rose rapidly over this period together with service activities. As a result only minor road transport decreases were caused by the structure of the GDP.

Finally, the effect of production linkages in Portugal, the UK, Germany and France (where $C^2 < C^2_{\text{mean}}$) is significant compared to the average. This shows that these countries changed their production processes, either by implementing technological innovations or by substituting inter-sector relationships. These changes reduced the dependence of their production on road freight transport. In contrast, Ireland and Finland are examples of the opposite trend as their production processes required a growing amount of tonne-kms, as seen in Fig. 1.

3.4. Effects of decoupling in the road transport sector

As seen in previous sections, decoupling factors have an impact on road freight transport demand. Therefore, new trends can be expected in terms of both structural business and organisation of the transportation industry. In order to highlight the most significant impacts of decoupling, Table 5 provides an analysis of the evolution of different key variables describing the situation of the transport industry over the period of study. This table shows the increase/decrease (in percentage) of the amount of transportation companies in each country, the value added at factor cost—the gross income from operating activities after adjusting for operating subsidies and indirect taxes, the gross operating surplus—understood as the gross output minus the cost of intermediate goods and services and minus the compensation for employees, and finally the number of employees.

From Table 5 we can obtain several findings that can add value to the results obtained in the previous sections. Firstly, looking at the evolution on the number of haulage companies, we observe that only in two countries—Ireland and mainly in Portugal—this ratio experienced a significant increase during the period of study. In these countries road freight transport demand has been continuously increasing and thus, clear coupling trends have been found (see Figs. 1 and 3). In contrast, there were fewer transport companies in 2007 than in 2000 in countries such as France, Italy or the United Kingdom. As seen above, we have found decoupling trends in these Member States (Fig. 2) along with a significant entry of foreign hauliers (see Table 3), clearly contributing to the loss of many national companies. These trends were accompanied by a reasonable evolution of the number of employees. In those countries where transport continued to grow at a pair of GDP (i.e. Ireland, Spain and Portugal) there was a greater recruitment of workers in the national transport industry. It is highlighted that the UK is the only case where the number of employees decreased during this period.

Focusing on the other two variables included in Table 5, we observe similar patterns. The value added of transport industry particularly increased in those countries where national hauliers moved greater amounts of goods across them (e.g. Spain and Portugal). It was the same case for the gross operating surplus. In other countries such as France or Italy these variables did not increase at the same high rates, or even have declined. This could be a consequence of the increasing competition in the transport sector due to the liberalisation process.

4. Conclusions

Several researchers noted the first signs of decoupling between road freight transport and economic growth in some countries during the 1980s and 1990s. Recent studies confirm that this situation has continued in certain European countries during the past few years.

In this paper we have developed a new methodology to go a step further in understanding both the key factors driving road freight transport trends in Europe at the macro level and the differences amongst countries. Thus, we have connected all the influencing variables on road transport: economic indexes—production, economic structure, intersectoral dependence,

imports or exports—and technological and logistic factors. On the basis of the implementation of the methodology to nine European countries, we have met the four objectives originally stated in the following way.

Firstly, we have identified the main coupling and decoupling factors in Europe over the past few years. In this respect, we have found that the evolution of GDP and international trade in Europe has contributed to increasing road freight transport demand. This is only reasonable in view of the fact that the greater the economic activity and trade, the higher the freight transport volumes. According to our method, the positive decoupling trends observed can be explained, as a whole, by (1) technological changes—that are prompting new sector linkages in production processes that require less exchange of goods—(2) the transition to more service-oriented economies has also led to a decline in road freight transport; and (3) the pursuit of efficiency in transport and supply systems—which has been measured through the road freight transport intensity (RFTI) ratio.

Particularly, we have noticed the effectiveness of RFTI evolution in decreasing final road freight transport demand in most countries; even though the entry of foreign haulers in some national road markets in Europe has significantly contributed to underestimate decoupling levels in some countries because the data available in transport statistics do not usually quantify this type of international transport. RFTI includes different aspects such as the average distance of the trips—based on the geographical location of production and consumption poles, the structure of the supply chain, the management of the transport system, and the evolution of the modal split. In this paper, we have provided a first overview of the similarities and divergences of the contributions of global values of RFTIs in road freight transport trends through a macro-analysis. Our results show that the evolution of the factors explaining RFTIs in the EU countries is diverse and cause different impacts in countries' road freight transport trends. Previous research works mentioned in this paper pointed out some similar patterns like the negligible contribution of modal split on the evolution of transport intensity, or the spatial concentration of production and inventory in most developed countries.

However, despite the fact that we have highlighted some possible reasons such as the shortening of the haulage distances in the UK or the increase in the value densities of Finnish goods, further analysis based on a micro approach would be necessary in order to improve the understanding of the mechanisms underlying RFTI trends in each country.

Regarding the second objective, in the light of the cross-country comparison, we can confirm that there are significant differences in Europe concerning decoupling. Taking into account both the national and the foreign transport activity, we have seen that in seven out of the nine countries analysed—Sweden, France, Italy, Ireland, Portugal, Spain and Germany—tonne-kms grew at almost the same rates or even higher rates than GDP between 2000 and 2007. In contrast, Finland and the UK have reached a strong decoupling level during this time as tonne-kms fell while GDP went up. Looking more in detail at the contribution of different decoupling factors, we notice that in just these two countries RFTI has had some of the most notable impacts in decreasing road freight transport demand. Something similar happened in Italy, but the increasing importance of foreign transport activity in this country counteracted this apparent decoupling. Nonetheless, this proves the relevance of RFTI in breaking the link between road transport and the economy.

Regarding the third and fourth objectives, our research has revealed that only few countries have decoupling levels greater than those detected in previous research works. This suggests that there is still huge potential to promote decoupling in Europe by reinforcing both the current trend through service economies and sustainable transformation of the manufacturing, logistical and transportation industries. As it was shown in our analysis, factors such as modal split have not played a key role yet in reinforcing decoupling in the EU so there is still room for keeping on promoting alternative more environmentally-friendly modes that may become decisive to improve sustainable mobility in the future.

Finally, we have confirmed that these decoupling trends are able to cause several impacts on the road industry such as the demise of transport enterprises. Therefore, national road sectors should be efficiently reorganized taking into account the expected demand and the external conditions like the extended international trade market in order to both maintain a sustainable business and continue to create value added in each country.

Appendix A

In the equilibrium equation of Leontief model we have the following expression:

$$x = (I - A)^{-1}f \quad (\text{A.1})$$

where x is the production vector of dimensions $(n \times 1)$, f $(n \times 1)$ the final demand vector (which includes domestic demand plus exports) and A the matrix of technical coefficients $(n \times n)$.

$(I - A)^{-1}$ is the Leontief inverse matrix $[L]$.

In the following we will denote the diagonalization by $\wedge$ and the transposition by $'$:

T is as a vector $(n \times 1)$ that contains the road transport demand by commodity class. Thus, we can define other vector whose elements express the road transport volume linked to each unit of sectorial output, that is to say, the road freight transport intensity—ton-kms/otuput:

$$t = T' \hat{x}^{-1} \quad (\text{A.2})$$

Thus, we can obtain the road transport volume in that way:

$$T = \hat{t}x \quad (\text{A.3})$$

Taking the value of x from the Eq. (A.1), it leads to:

$$T = \hat{t}(I - A)^{-1}f \quad (\text{A.4})$$

On the other hand, in an IO model, the final demand is equal to the sum of the GDP plus the volume of imports. So, the vector f can be expressed by other two vectors ($n \times 1$) that contain these components sorted by sector.

$$T = \hat{t}(I - A)^{-1}(GDP + Imp) \quad (\text{A.5})$$

Let $\bar{s} = (\bar{s}_1, \bar{s}_2, \dots, \bar{s}_n)$ be a vector of the sectorial shares of GDP of n productive sectors, so that $\sum_i \bar{s}_i = 1$. Therefore, the road freight transport demand can be expressed by five components: the road freight transport intensity, the production structure—that is to say, the technological linkages, the GDP structure, the aggregate GDP value and the volume of imports, as is shown in expression (A.6).

$$T = \hat{t}(I - A)^{-1}(\bar{s}\Sigma GDP + Imp) \quad (\text{A.6})$$

Our objective is to study the factors that motivate the differences, in terms of aggregate road transport demand, between two years—expressed by superscripts 0 and 1—along a temporary period. This means that our objective is to explain $\Delta T_{0-1} = T^1 - T^0$.

According to Dietzenbacher and Los (1997), if any factor $-y-$ is expressed by the product of n variables— $x_1, x_2, \dots, x_n$, the observed changes over the period 0–1 leads to the following decomposition:

$$\begin{aligned} \Delta y = & \left(\frac{1}{2}\right)(\Delta x_1)[(x_2^0 \dots x_n^0) + (x_2^1 \dots x_n^1)] + \left(\frac{1}{2}\right)[x_1^0(\Delta x_2)(x_3^0 \dots x_n^0) + x_1^1(\Delta x_2)(x_3^0 \dots x_n^0)] + \dots \\ & + \left(\frac{1}{2}\right)[(x_1^0 \dots x_{n-2}^0)(\Delta x_{n-1})x_n^1 + (x_1^1 \dots x_{n-2}^1)(\Delta x_{n-1})x_n^0] + \left(\frac{1}{2}\right)[(x_1^0 \dots x_{n-1}^0) + (x_1^1 \dots x_{n-1}^1)](\Delta x_n) \end{aligned} \quad (\text{A.7})$$

So, by applying this rule to de Eq. (A.6), we can write our expression to carry out the SDA on road transport demand:

$$\begin{aligned} \Delta T^{0-1} = & \left(\frac{1}{2}\right)(\Delta \hat{t})^{0-1}[L^0(\bar{s}^0 \Sigma GDP^0 + Imp^0)] \\ & + \left(\frac{1}{2}\right)[\hat{t}^0(\Delta L)^{0-1}(\bar{s}^1 \Sigma GDP^1 + Imp^1) + \hat{t}^1(\Delta L)^{0-1}(\bar{s}^0 \Sigma GDP^0 + Imp^0)] \\ & + \left(\frac{1}{2}\right)[\hat{t}^0 L^0(\Delta \bar{s})^{0-1} \Sigma GDP^1 + \hat{t}^1 L^1(\Delta \bar{s})^{0-1} \Sigma GDP^0] + \left(\frac{1}{2}\right)[(\hat{t}^0 L^0 \bar{s}^0) + (\hat{t}^1 L^1 \bar{s}^1)](\Delta \Sigma GDP)^{0-1} \\ & + \left(\frac{1}{2}\right)[(\hat{t}^0 L^0) + (\hat{t}^1 L^1)](\Delta Imp)^{0-1}. \end{aligned} \quad (\text{A.8})$$

Appendix B

Table B.1

Sectorial contributions to changes in road freight between 2000 and 2007.

	C ¹	C ²	C ³	C ⁴	C ⁵	Total
<i>Germany</i>						
1. Food, beverage and tobacco	−7.25	−1.10	−0.64	+11.44	+3.18	+5.63
2. Mining	−15.11	−1.08	+1.19	+8.53	+8.17	+1.70
3. Textile sector	+0.25	−1.27	−2.43	+5.60	+1.57	+3.72
4. Wood industry	−1.17	−0.10	−0.14	+1.47	+0.71	+0.77
5. Papers and printing	−0.05	−0.18	−0.02	+0.57	+0.18	+0.49
6. Energy goods	−4.34	+0.69	+0.41	+1.52	+1.45	−0.27
7. Chemical products	−3.31	−0.81	+0.88	+4.10	+2.07	+2.93
8. Machinery and transports	−3.47	−0.14	+0.83	+3.87	+2.08	+3.17
9. Manufacturing	−1.34	+0.18	−0.56	+2.05	+0.60	+0.94
10. Construction products	−3.21	−0.47	−1.68	+3.97	+0.57	−0.83
11. Service products	−3.01	−0.17	−0.23	+7.41	+1.34	+5.35
Total	−42.00	−4.44	−2.37	+50.51	+21.93	+23.63

Table B.1 (continued)

	C ¹	C ²	C ³	C ⁴	C ⁵	Total
<i>Spain</i>						
1. Food, beverage and tobacco	−5.38	−3.55	−5.99	+31.85	+4.52	+21.43
2. Mining	−8.08	+0.93	+0.34	+16.53	+8.44	+18.16
3. Textile sector	+3.58	−1.09	−5.19	+8.62	+0.90	+6.83
4. Wood industry	−2.38	−0.80	+0.12	+1.86	+0.60	−0.60
5. Papers and printing	−0.02	−0.12	−0.06	+0.60	+0.14	+0.54
6. Energy goods	−4.20	+0.66	−0.23	+2.29	+2.79	+1.32
7. Chemical products	−3.31	−1.29	−0.01	+5.88	+2.19	+3.46
8. Machinery and transports	−0.12	+0.27	−1.68	+6.46	+2.44	+7.37
9. Manufacturing	−1.78	+0.51	−1.01	+2.29	+0.66	+0.67
10. Construction products	−8.11	+2.79	+3.35	+9.87	+1.28	+9.19
11. Service products	−9.77	+0.59	+0.21	+12.95	+1.72	+5.70
Total	−39.56	−1.10	−10.15	+99.20	+25.68	+74.07
<i>Finland</i>						
1. Food, beverage and tobacco	−10.37	−0.93	−1.28	+9.47	+2.21	−0.90
2. Mining	−19.37	−0.03	+1.28	+7.64	+9.77	−0.71
3. Textile sector	−4.49	−0.60	−3.11	+5.48	+0.93	−1.80
4. Wood industry	−21.87	+2.69	−3.76	+13.57	+3.66	−5.71
5. Papers and printing	−1.05	−0.22	−0.38	+1.04	+0.19	−0.42
6. Energy goods	−4.45	+0.65	+0.08	+1.98	+2.86	+1.12
7. Chemical products	−5.68	−0.69	+0.47	+3.67	+1.85	−0.39
8. Machinery and transports	−1.18	−0.30	−0.15	+1.84	+0.92	+1.13
9. Manufacturing	−0.55	+0.12	−0.25	+0.81	+0.36	+0.48
10. Construction products	−4.92	+0.00	+0.93	+3.75	+0.71	+0.46
11. Service products	−8.97	+0.45	+0.22	+6.93	+1.38	±0.00
Total	−82.90	+1.13	−5.96	+56.18	+24.83	−6.74
<i>France</i>						
1. Food, beverage and tobacco	−11.92	−1.79	−2.72	+15.94	+2.01	+1.52
2. Mining	−8.17	−0.82	−0.40	+7.67	+3.91	+2.19
3. Textile sector	−2.83	−0.69	−3.13	+4.89	+0.30	−1.47
4. Wood industry	−1.71	−0.17	−0.14	+1.40	+0.48	−0.14
5. Papers and printing	−0.32	−0.12	−0.07	+0.35	+0.07	−0.10
6. Energy goods	−2.75	+0.45	−0.39	+1.60	+1.60	+0.51
7. Chemical products	−5.55	−0.52	−0.18	+3.59	+1.30	−1.36
8. Machinery and transports	−3.95	−0.27	−0.93	+3.17	+0.90	−1.08
9. Manufacturing	−1.89	+0.02	−0.31	+1.54	+0.43	−0.21
10. Construction products	−4.23	+0.23	+1.04	+3.93	+0.59	+1.56
11. Service products	−13.81	+0.78	+0.73	+16.58	+1.76	+6.04
Total	−57.12	−2.92	−6.50	+60.66	+13.34	+7.46
<i>Ireland</i>						
1. Food, beverage and tobacco	−11.47	−4.74	−6.61	+24.79	+9.33	+11.29
2. Mining	−4.10	+2.03	−3.36	+12.91	+9.72	+17.21
3. Textile sector	+1.04	+0.19	−5.94	+6.86	+1.00	+3.16
4. Wood industry	−0.85	−1.77	+0.63	+2.40	+1.67	+2.08
5. Papers and printing	+0.11	+0.00	−0.02	+0.04	+0.03	+0.16
6. Energy goods	−13.38	+4.26	+0.57	+4.51	+5.58	+1.55
7. Chemical products	−3.38	+1.04	−1.87	+3.48	+1.57	+0.84
8. Machinery and transports	+2.24	+0.64	−1.61	+2.72	+1.32	+5.31
9. Manufacturing	−2.25	+0.20	−0.09	+0.75	+0.97	−0.41
10. Construction products	−10.70	+0.08	+3.89	+9.30	+2.92	+5.49
11. Service products	−18.81	+1.09	+3.98	+14.63	+6.86	+7.74
Total	−61.56	+3.03	−10.43	+82.40	+40.98	+54.42
<i>Italy</i>						
1. Food, beverage and tobacco	−14.25	−1.61	−2.15	+12.99	+2.87	−2.14
2. Mining	−14.25	−1.61	−1.51	+13.39	+1.84	−0.22
3. Textile sector	−21.43	+0.07	+0.72	+12.84	+7.58	−0.43
4. Wood industry	−3.18	−0.26	−1.50	+4.06	+0.46	−0.53
5. Papers and printing	−1.98	−0.33	−0.19	+1.47	+0.49	−0.06
6. Energy goods	−1.10	−0.20	−0.12	+1.11	+0.25	+0.28
7. Chemical products	−3.94	+0.67	−0.50	+1.62	+2.43	−0.78
8. Machinery and transports	−5.42	−0.71	−0.43	+4.10	+1.68	−1.04
9. Manufacturing	−4.06	−0.09	−0.03	+2.46	+0.69	−0.92
10. Construction products	−2.75	+0.07	−0.61	+1.93	+0.45	+1.06
11. Service products	−6.63	+0.25	+0.84	+5.85	+0.75	+1.92
Total	−72.22	−2.01	−3.04	+56.72	+17.71	−2.85

(continued on next page)

Table B.1 (continued)

	C ¹	C ²	C ³	C ⁴	C ⁵	Total
<i>Portugal</i>						
1. Food, beverage and tobacco	+0.62	−3.34	−1.33	+14.09	+3.16	+13.21
2. Mining	−10.55	−2.58	+1.19	+14.41	+9.11	+11.57
3. Textile sector	+5.30	−1.78	−5.12	+9.02	+0.51	+7.93
4. Wood industry	−1.46	+0.10	−0.47	+3.57	+0.99	+2.73
5. Papers and printing	−0.42	−0.17	−0.09	+0.69	+0.20	+0.20
6. Energy goods	−3.06	+1.28	+0.02	+1.28	+2.20	+1.72
7. Chemical products	+0.11	−0.53	+0.74	+3.29	+2.03	+5.64
8. Machinery and transports	+0.07	−0.48	−0.93	+5.37	+3.43	+7.46
9. Manufacturing	+0.58	−0.51	−0.25	+3.18	+1.01	+4.01
10. Construction products	−2.21	+0.76	−1.88	+6.68	+0.87	+4.22
11. Service products	+3.23	+0.02	+0.65	+8.76	+1.16	+13.83
Total	−7.79	−7.22	−7.47	+70.35	+24.66	+72.52
<i>Sweden</i>						
1. Food, beverage and tobacco	−4.90	−1.37	−1.88	+8.57	+2.13	+2.54
2. Mining	−8.34	+0.19	+1.31	+4.89	+4.23	+7.29
3. Textile sector	−2.83	−0.45	−1.72	+3.81	+0.60	−0.59
4. Wood industry	−15.04	+0.82	+1.49	+10.74	+4.62	+2.64
5. Papers and printing	−0.60	−0.21	−0.22	+0.77	+0.21	−0.05
6. Energy goods	−3.87	−0.06	+0.45	+1.51	+1.66	−0.31
7. Chemical products	−3.87	−0.14	−0.08	+2.30	+1.10	−0.68
8. Machinery and transports	−2.96	−0.05	−0.39	+2.45	+1.18	+0.23
9. Manufacturing	−0.18	−0.10	−0.25	+0.88	+0.40	+0.73
10. Construction products	−3.17	−0.19	+0.91	+2.06	+0.85	+4.44
11. Service products	−10.99	+0.29	+0.00	+14.73	+3.22	−1.75
Total	−56.75	−1.28	−0.39	+52.70	+20.20	+14.49
<i>United Kingdom</i>						
1. Food, beverage and tobacco	−18.31	−1.03	−6.24	+16.97	+1.82	−6.80
2. Mining	−4.79	−1.74	−1.50	+6.29	+2.31	+0.58
3. Textile sector	−2.48	−1.39	−5.31	+6.20	+0.08	−2.90
4. Wood industry	−1.74	−0.26	0.02	+1.06	+0.32	−0.60
5. Papers and printing	−0.01	−0.13	−0.08	+0.33	+0.04	+0.15
6. Energy goods	−5.63	+0.13	−0.05	+2.47	+1.36	−1.72
7. Chemical products	−3.85	−0.36	−0.72	+2.84	+0.59	−1.50
8. Machinery and transports	−2.69	−0.22	−2.18	+3.23	+0.46	−1.41
9. Manufacturing	−1.24	−0.14	−0.41	+1.14	+0.22	−0.45
10. Construction products	−4.50	−0.48	+0.97	+3.35	+0.45	−0.20
11. Service products	−17.11	+0.49	+1.17	+11.63	+1.53	−2.30
Total	−62.34	−5.13	−14.34	+55.52	+9.17	−17.13

All contributions are given in % of tonne-kms between 2000 and 2007.

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4. CONCLUSIONS AND FUTURE RESEARCH

This section summarizes the fulfilment of the objectives (Section 4.1), enumerates the main conclusions and recommendations (Section 4.2 and 4.3), and proposes further research that could follow up this thesis (Section 4.4).

4.1. Fulfillment of the research objectives

As previously explained in Chapter 1, the main objective of this thesis was to provide knowledge for explaining European road freight transport decoupling trends and identifying key drivers boosting it during the last few decades. To that end, this thesis reached the following achievements:

- (i) Firstly, it found current evidences that verify the continuation of the decoupling trends previously noted in preceding research works.
- (ii) It identified the key drivers of road freight transport trends and analysed the likely impact of their evolution in reinforcing decoupling road freight transport from economic growth. At this point, the special focus was twofold: analyse the impact of the evolution of road freight intensities and explore the potential effect of the economic restructuring processes through service-oriented economies.
- (iii) It provides a cross-country comparison in order to characterize the countries with both highest and lowest decoupling levels in Europe and it finds out reasons for similarities and divergences.
- (iv) It identifies useful tools for this type of top-down analysis in the transport sector.

In order to fulfil the goals, a new methodology was proposed and validated for different European case studies. Several papers were produced with a common structure: introduction, objectives and state of knowledge, methodology and data, application to the case studies, discussion and conclusions.

Regarding the first objective, the starting point of this research work consisted of a comparison analysis between the decoupling levels of road freight transport in different case studies in order to check whether past decoupling trends noted in previous pieces of literature have remained stable in Europe during the last few years.

- a) Following the traditional practice of studying decoupling by means of analysing the transport intensity ratio, the first paper (Chapter 2) developed a macro analysis focused on comparing the evolution of the road tonne-kms/GDP relationship in the United Kingdom and Spain from 1999 to 2007 by studying the evolution of both sectorial road freight transport intensities and economic structure in each country. Through a decomposition analysis the main reasons of the decoupling levels in each country were found. This analysis revealed stable decoupling trends but at different levels in these two countries.
- b) In addition, the analysis conducted in the third paper (Chapter 3) involved the characterization of the decoupling levels of nine European countries and the confrontation with the observed decoupling/coupling states for these same countries in previous literature.

Concerning the second and third objectives, this research work developed a new methodology to go a step further in understanding both the key factors driving road freight transport trends in Europe at the macro level and the differences observed across countries. The analysis carried out intended to identify the decoupling factors in European countries during last decade.

- c) The exercise developed in paper 2 (Chapter 2) was aimed at measuring how changes in the structure of the economy affects road freight transport trends at the macro level in a certain geographical areas. For this purpose,

a simulation analysis was implemented through the definition of two confronting scenarios that reflect a hypothetical evolution of the structure of the economy —towards a full dematerialization or a full materialization. This was applied to two case studies: Spain and the UK in order to determine how road freight transport would behave under these hypothetical situations in these two countries in comparison with current trends. Therefore, the impact of the economic restructuring processes on decoupling was explored in detail.

- d) Through an Input-Output structural decomposition analysis (SDA), the third paper (Chapter 3) assigned road freight tonne-kms changes over time to the key drivers of road freight transport demand in European countries. This analysis allowed identifying the factors that have played the greatest role in explaining road freight transport trends and promoting coupling/decoupling levels. This was particularly focused on economic indexes—production, economic structure, intersectoral linkages, imports and exports— and road freight transport intensities as explanatory variables.

Finally, the fourth objective consisted of identifying the most suitable tools for developing the analysis. The research approach of this thesis is based on a new methodology that combines Input-Output (IO) tables with transport information through the definition of an extended IO model. This method, that was presented in paper 2 (Chapter 2), and was afterwards applied for the analysis carried out in paper 3 (Chapter 3), provides a useful tool for explaining the evolution of road freight transport at the macro level in different countries. This may be of special interest for both transport stakeholders and policy makers from a top-down approach.

4.2. Methodological recommendations and achievements

Given the use of the described techniques not yet applied to macro analyses in the transportation field, the following conclusions show the methodological contributions for better knowing the evolution of the road freight transport behaviour.

- Selection of methodologies. Freight activity depends on production processes and trade relationships and, as a consequence of that, numerous transport models using Input-Output (IO) data have appeared in the transport literature and practice. IO tables are designed based on supply and demand representing intersectorial linkages in production/consumption.

Regarding the macro approach for analysing freight transport demand, this thesis proposes the use of an IO model. This procedure makes possible an accurate representation of the interchange of goods —trade flows— and therefore the movement of goods in a region. In addition, IO information is linked with road freight transport intensity data. This method allows considering both economic activity and transport systems features in order to understand road freight transport behaviour in each country.

- Data usage. The selection of a procedure to analyse road freight transport is highly dependent on data availability. Within the transport field, numerous authors have integrated IO data into freight transport demand models (see Cascetta et al. (1996), Wang (2004) and Giuliano et al. (2007). All these authors claim that the flows of goods and services collected in the tables are equivalent to a specific number of trips between supply and demand zones (Holguín-Veras and Thorson 2007). The commodity-based approach considering the amounts of both commodity production and consumption results in more realistic and accurate freight demand models (Wisetjindawat et al. 2006). Nevertheless, certain difficulties are found in some of the cases:

there are not enough data to support this approach neither is there enough disaggregation level. For instance, in an IO table supply and demand data for the transport sector does not differentiate between flows of passengers and freight hence impeding the development of forecasting models for each one of them. In the same way, modelling the demand of goods and services requires converting IO monetary sectorial transaction flows into physical units.

IO tables can be extended or modified in order to overcome certain limitations for carrying out specific studies. With the aim of analysing freight transport demand at the macroeconomic level, this research applied an extended IO model that converts gross output by commodity class into the equivalent volumes of transport.

This research has implied handling a great amount of data. Specifically, two types of data have been collected for all the case studies: annual IO tables and annual transport series for the periods of review—tonnes, tonne-kms and veh-kms— sorted by commodity for each case study. As long as the proposed methodology requires the combination of these two types of information, it is mandatory that both data reflect an identical disaggregation level. Therefore, in order to homogenize the two databases into the same groups of industries/commodities, the first step consisted of checking the list of commodity groups included in the transport dataset that could be assigned to the output of either an industry or a group of industries of the IO tables. In that way both data were managed by aggregating them into the same sectors. It is true that the classificatory schemes were very different and this is the reason why the analysis have been done based on eleven sectors (papers 1 and 3) and eight sectors (paper 2) instead of either the 35 industries of the IO tables or the 24 commodity groups of transportation series.

An example of the aggregation procedure for an economic branch is shown in Table 4.1

Table 4. 1. Aggregation of IO groups' data and transport volumes combined for defining the group of Food, beverage and tobacco in developed analysis

Sector for analysis: Food, beverage and tobacco	
IO industries	Transported commodities
i. Agriculture, Hunting, Forestry and Fishing	01 Cereals
ii. Food, Beverages and Tobacco	02 Potatoes, other fresh or frozen fruits and vegetables
	03 Live animals, sugar beet
	06 Foodstuff and animal fodder
	07 il seeds and oleaginous fruits and fats

- Data limitations. The available data for developing any objective analysis does not always cover all the needs and does not include all the required variables at the necessary disaggregated level. Therefore, despite the estimation procedures that could be used when complete data is not available, data limitations should be considered in drawing conclusions.

For instance, difficulties were found in accessing quality, reliability and complete data about both value densities and handling factors as key explanatory variables for freight transport intensities, and hence, for road freight transport decoupling trends. Regarding this, a composite index is applied in paper 2 (Chapter 2) for the case studies under review: tonnes_lifted/Output (\$), equal to the product of the inverse value density and the handling factor.

On the other hand, when determining the levels of road freight transport decoupling in a country, available transport data usually exclude the transport activity (both dispatch and receipt) carried by foreign-registered vehicles in a country. This issue should be taken into account since this may led to overestimations of national decoupling levels. This issue was widely discussed in Chapter 3.

- Identification of key explanatory factors. The estimate of road freight transport demand is usually based on GDP growth. Nevertheless, this issue is much more complex since road freight transport is affected by a wide variety

of factors determining the shipping of commodities in each country. Effects such as technological innovations, changes in final demand or logistic improvements may contribute to modifying transport patterns. Hence, it is necessary to identify which are the most influential factors in each case when analysing transport trends. Through the current dissertation, different key factors were identified from a macro point of view. At national level, factors influencing road freight transport were: road freight transport intensities, intersectoral linkages, GDP structure, economic growth and international exchange of goods (Chapter 3).

- Decomposition techniques. Available national statistics and annual national IO tables serve to analyse the evolution of the key coupling and decoupling factors and road freight transport demand over the periods of review. The combination of these factors into a decomposition methodology shows the main drivers influencing road freight transport trends in Europe. In this thesis this technique was chosen for its capacity to incorporate the underlying factors that cause decoupling trends and for its consistency in periods where changes occur (i.e. changes in supply and transport technology or in the economy).

The general equation used to define road freight transport in a year t was the following:

$$T_t = \widehat{RFTI}_t L_t [\bar{s}_t \sum GDP_t + Imp_t]$$

Thus by applying the SDA technique it is possible to break down the aggregate changes in road freight transport demand in a particular economy into the contributions of five main factors, namely: (1) changes in road transport intensities (RFTI); (2) variation in production linkages depending on the inter-sector relationships described by [L]; (3) changes in GDP structure, that is to say, the sector share of total GDP ($\bar{s}$); (4) global growth or decrease in GDP; and (5) changes in import volumes (Imp). They were the main drivers influencing road freight transport.

In conclusion, the dissertation suggested that a decomposition analysis should constitute the first step when analysing road freight transport demand in order to identify key drivers and design decoupling strategies at the national level.

- Simulation analysis. The simulation exercise developed in this thesis (Chapter 2), allowed testing whether structural changes in national economies are effective on the promotion of decoupling between road freight transport and economic development. The assessment is based on the comparison of the road freight transport volumes for different scenarios—in which different evolution of GDP structure occurred—with the reference to the current trends. Thus, other strategies using this approach can be proposed and tested in order to better design and assess policies—during the planning, design, operational phases—focused on achieving greater decoupling levels.

4.3. Research findings and conclusions

Throughout this thesis different analysis are applied to several case studies of the European Union in order to identify the main drivers of road freight transport and to provide a comparison analysis of road decoupling levels. These analyses yielded some interesting conclusions and contributions summarised in this section.

- a) The decoupling trends found between GDP growth and road freight transport volumes demonstrate that aggregate economic variables such as global GDP are alone unable to explain the evolution of road transport demand over time. The global volumes of road freight transport recorded in a country depend on the volumes of gross outputs exchanged among its economic branches and with other countries. New technological innovations, new production processes and variations of the goods consumed in a country may cause restructuring processes of the economy that might

increase/decrease these gross outputs. These effects contribute to modify national and international transport patterns.

- b) Among all the economic sectors of an economy, it is possible to distinguish between transport-intensive sectors like agriculture or mining —that is, sectors largely depending on shipment of commodities— and non-transport-intensive sectors like services. Within this context, economic sectors can be characterized by means of the “*road freight transport intensity*” (RFTI) index, that provides a measurement of the volume of road transport related to sectorial production, i.e., tonne-kms or veh-km per unit of sectorial output.
- c) Those countries evolving to service-oriented economies show higher levels of decoupling between freight transport growth and economic growth. That is to say, freight traffic grows at lower rates than the economy. In contrast, in those economies predominantly based on primary and secondary sectors, such as agriculture, construction or manufacturing, freight transport demand usually couples with economic expansions.

The comparison analysis between Spain and the UK showed that although both countries have been shifting from manufacturing to service economies, the impact of the growth of the construction and its linked sectors in Spain significantly contributed to curb decoupling by increasing the percentage of tonnes lifted.

Figure 4.1 gives an overview of the main economic sectors in the national output in both economies —the UK and Spain— by showing graphically the national 2007 IO tables. It is seen how monetary transactions between service sectors (red bars in either the UK or Spanish graphs) make the most important contribution to the UK economy. In contrast, the main economic sector in Spain’s national output is construction (the highest green bar). The real GDP growth and the road tonne-kms trends in both countries are also shown. The effect mentioned above is clear: while the growth of real GDP in the period 1999-2007 led to a 95% rise in road freight transport in Spain, the

volume of tonne-kms decreased by 7% in the United Kingdom under an economic growth scenario.

Source: Own elaboration

Figure 4.1. Input-output transaction tables with economic transactions among industries shown in US\$ (2007) (above) and growth in real GDP and road tonne-kms in the United Kingdom and Spain (below) (index 1999=100): 1999-2007.

d) The value of sectorial RFTIs in a country depends on several technological, logistical and organizational factors of production processes and transport operations. For instance, it depends on the mix and value of produced goods, the design of the supply chains, the location of production and consumption centres, the modal split and the effectiveness in using transport resources. The divergences among countries together with the temporal evolution of these factors lead to very different sectorial RFTI values across countries and over time.

From the comparison analysis of UK and Spain developed in this research, it is concluded that RFTI experienced a sharper decrease in the UK than in Spain throughout the period of study 1999 to 2011 (see Figure 4.2). With the

exception of the load factor, the rest of the ratios showed more efficient values in the UK than in Spain

Regarding the amount of tonnes lifted per unit of monetary production, that is the freight intensity ratio, the mean value was 68% higher in Spain than in the UK. In the UK this ratio has been steadily decreasing ever since 1999, and in contrast, this significantly increased in 2002 in Spain due to the expansion of the construction activity. It is noted that mining and construction goods are low value materials and generate numerous as well as short-length trips. Thus, this also contributed to the remarkable reduction of the average length of haul recorded in the country from 2001 and 2002.

On the other hand it is worth noting that modal share remained stable in both countries, slightly contributing to decoupling trends.

Source: Own elaboration

Figure 4.2. Evolution of global RFTI —veh-km/output— and related ratios from 1999 to 2011 in Spain and the UK. Index 1999=100

e) Regarding the analysis of the key drivers of road freight transport trends in Europe, several conclusions along with common patterns and divergences across the case studies of this work are found:

- As a whole, the growth of GDP and imports in Europe has contributed to increasing road freight transport demand. This is reasonable in view of the fact that the greater the economic activity and trade, the higher the freight transport volumes. However, the positive decoupling trends can be explained by (i) technological changes prompting new sector linkages in production processes less dependent on shipping commodities; (ii) the transition to more service-oriented economies; and (iii) the search of transport efficiency.
- Among all the decoupling contributions found in this work, it is highlighted that the most effective one in constraining road freight traffic growth during the last few years has come from the evolution of RFTIs in most EU countries. In countries like Finland and the UK, RFTI had the most notable impact on decreasing road freight transport demand in past years. Something similar happened in Italy, but the increasing importance of foreign transport activity in this country counteracted this apparent decoupling. At this point is essential to highlight that the entry of foreign-registered trucks in some countries had been partly responsible for overestimating the decoupling levels measured in some countries.
- A classification of EU countries based on the degrees of coupling and decoupling of transport volume growth from economic growth has been provided: countries like the UK and Finland, which showed a situation of weak decoupling in the 90s, achieved a strong decoupling level in the last years. Other countries —Portugal, Spain, Germany and Ireland— remain in an expansive negative decoupling state as already was observed in previous research works. It is noted that Ireland is very close to achieve the next region of expansive coupling. Sweden and France however have evolved to a weak decoupling level. This analysis appears in Figure 4.3.

Source: Own elaboration based on Eurostat statistics

Figure 4. 3. Level of decoupling of freight transport volume from GDP in EU countries from in 2007

- f) Finally, regarding the analysis of the effectiveness of economic structural changes on the promotion of decoupling through a simulation exercise, I found that economic restructuring processes in national economies may play a significant role in determining final road freight transport volumes. For the same global GDP growth, very different road transport volumes may be expected depending on the type of economic activity developed in a certain country. In this regard, the empirical analysis carried out demonstrated that the UK has attained an almost absolute decoupling level while structural changes in Spain's GDP still have an important potential to contribute to decoupling in the future.

4.4. Future research

This research has identified a number of issues which could be the object of future research. The following areas should be pursued to expand the current research.

- On the analysis of the key drivers of road freight transport:
 - Further research is needed in order to explore the performance of additional explanatory variables, as well as their likely potential to determine road freight demand evolution over time. This contribution would be highly useful for estimating more accurate traffic forecasts; as well as for providing information for better policy design and a more reliable management of road traffic for future periods.
 - As this research is focused on road freight transport from national economic activity, complementary analysis of international trade needs to be extended. Since production processes are characterized by international fragmentation leading to an interdependent structure, this is required to be accounted for as a key driver of international freight transport trends. This research extension could be made by means of Intercountry Input-Output tables. These combine detailed information on national production activities and international trade data. That analysis could be of special interest not only for defining cross-country island traffic or cabotage, but for understanding the key drivers of the trends of other transport modes such as maritime transport.
 - Regarding the impacts of economic restructuring processes in road freight transport trends, future research is required to carry out sensitivity analysis of different changes in the rest of identified drivers. As it has been noted in this thesis, further analysis based on a micro approach is necessary in order to improve the understanding of the mechanisms underlying road freight transport intensity trends in each country.

- On the analysis of modelling future road freight demand through a macro approach

By using the proposed IO extended model to define road freight transport demand, a better forecasting analysis could be conducted in order to explore future trends. For this purpose IO tables and road freight transport intensity ratios should be estimated in the future.

Regarding the issue of the stability of IO data, although authors such as Marzano and Papola (2008) hold that technical coefficients show a scarce temporal variability for a time horizon of less than ten years —that implies that they can be considered as almost fixed values—, it is worth noting that most studies carried out have generally looked for the most up to date IO data available (Miller and Blair 2009). Their possible changes in the short term as a consequence of economic factors may introduce errors in forecasting models. These have been addressed by updating IO tables through the analysis of the trends in IO coefficients and regression models run on historical data (Voigtlaender 2002). However, extrapolation of technical coefficients has been proven to provide worst results than using the most recent available IO data (Miller and Blair 2009).

Early work at updating IO information has led to one of the most widely-used procedure: the RAS method (also known as a “biproportional” matrix balancing technique), designed under Stone’s direction (Stone and Brown 1962). This is thought to update the IO direct input coefficients table of a given year in the past to a more recent year.

This methodology has been already applied for developing several demand forecasting studies. For instance, Wei et al. (2006) and Fan et al. (2007) used the RAS method to compute China’s energy requirements and CO₂ emissions in 2010 and 2020 based on the IO table of 1997. Fan and Xia also applied the RAS technique to a hybrid energy IO model (2012) to analyse energy intensity for 2020 in the same country based on the projected economic growth rates since 2010.

Therefore, forecasting analysis in the transportation field could be addressed by applying IO RAS method together with other selected techniques to estimate road freight transport intensities evolution in a specific country.

5. ABBREVIATIONS AND ACRONYMS

ARMA	Auto-Regressive Moving Average
BCA	Benefit-Cost Analysis
CBA	Cost-Benefit-Analysis
CEA	Cost-Effectiveness Analysis
EEA	European Economic Area
EU	European Union
EC	European Commission
GDP	Gross Domestic Product
ICT	Information and Communication Technology
IO	Input-Output
JIT	Just-In-Time
LCCA	Life-Cycle Cost Analysis
MCA	Multi- Criteria Analysis
OECD	Organisation for Economic Co-operation and Development
QR	Quick Response
REDEFINE	RElationship between DEMand for Freight-transport and INdustrial Effects
RFT	Road Freight Transport
RFTI	Road Freight Transport Intensity
SACTRA	Standing Advisory Committee on Trunk Road Assessment
SDA	Structural Decomposition Analysis
TI	Transport Intensity
UK	United Kingdom

US	United States
VAR	Vector Auto Regression
WIOD	World Input-Output Database
UPM	Universidad Politécnica de Madrid

6. COMPILED REFERENCES

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