Economic Systems Research

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cesr20

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To cite this article: José L. Zofío, Julio González, Angel Prieto & Juan Vicente (2021): Modelling the spatial and sectoral benefits of productivity enhancing innovations using a transport oriented multiregional IO framework: the ‘megatruck’ in Spain, Economic Systems Research, DOI: 10.1080/09535314.2021.1951178

To link to this article: https://doi.org/10.1080/09535314.2021.1951178

Published online: 22 Jul 2021.

ECONOMIC SYSTEMS RESEARCH
https://doi.org/10.1080/09535314.2021.1951178

Modelling the spatial and sectoral benefits of productivity enhancing innovations using a transport oriented multiregional IO framework: the 'megatruck' in Spain

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ABSTRACT

We render operational the model outlined by Carter (1990) via the introduction of the research methods necessary for studying the spatial and sectoral (upstream and downstream) benefits of productivity-enhancing innovations within a real interregional input–output framework. As case study we examine the reduction in production costs derived from the adoption of longer and heavier vehicles in freight road transportation. We exploit a new Spanish regional table including a detailed disaggregation of the transportation sector. The productivity gains at the national level, resulting from a 30% reduction in transport costs, amount to 2.95% of the GVA at market prices. Results show that firms operating in this niche market appropriate most of the gross operation surplus (which increases by 10%), consistent with the existence of market power. The remaining transportation sectors see profits slightly worsened, suggesting limited substitution effects. A high regional heterogeneity exists because of the different input–output structures.

ARTICLE HISTORY
Received 9 October 2019
In final form 30 June 2021

KEYWORDS
Multiregional input–output table; innovation; productivity; transportation; megatruck

1. Introduction

This paper introduces methods that allow the analysis of the economy-wide benefits of innovations that modify the structure of production costs for road freight transportation within a regional input–output (IO) table. The analysis relies on an enhanced version of the regional Spanish IO table that details the transportation sector by modes as well as goods and passengers. Inspired by the approach outlined by Carter (1990), we show how the benefits emanating from the productivity gains arising from the adoption of longer and heavier vehicles in the form of input savings, are distributed through the economy. Either in the form of higher margins, lower prices, or a combination of the two, depending on the product and demand elasticities. Transportation costs constitute one of the main factors of intermediate production for goods distribution, and therefore it is expected that

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Supplemental data for this article can be accessed here. https://doi.org/10.1080/09535314.2021.1951178

any innovation in this sector translates itself into larger economy-wide effects via existing industrial and spatial linkages.

As production costs diminish, several spillover effects in the form of backward and forward linkages can be defined to determine the change in key economic variables across sectors and regions. The absolute and relative changes grant a vision of how disruptive any given innovation is within the system, to what extent it is beneficial to society and ultimately, who reaps the profits from it. By focusing on cost savings, this study resorts to a dual definition of productivity change that captures the economic effects that technological progress brings to the economy, rather than primal definitions that rely only on quantities. From a primal perspective, technological advances result in the joint increase of output quantities together with reductions in input quantities. In line with index number theory, these changes can be measured through productivity indices that are conventionally defined as the ratio of an output quantity index to an input quantity index.[1] The fact that these indices allow the aggregation of all production inputs explains why they are known as total (multi-)factor productivity measures. On the contrary, in IO analysis, productivity gains are ultimately determined through changes in economic aggregates, both from the output and input sides. On the output side, these aggregates are customarily represented by macro-economic magnitudes (e.g. GDP, GVA, operating surplus, etc.). Following Carter (1990), we measure productivity as the output growth in terms of the firm operating surplus originated by the cost savings arising from innovations, mainly in the form of reductions in labour and energy input.

How the benefits of these changes in productivity are distributed throughout the sectoral and regional IO framework is our main research focus. Specifically, we study whether the innovative sector can appropriate them in the form of a higher operating surplus, or alternatively, whether they permeate through the economy benefiting other sectors and consumers in the form of lower prices. To achieve this goal, we operationalize Carter's (1990) analytical model and show how it can be implemented using a real-life application of relevant innovation. From a methodological perspective, we enhance her analysis, which she exemplified with a hypothetical IO table with just four sectors and two primary inputs. We apply it to an actual multiregional IO table consisting of 19 regions, each with 35 sectors. For this purpose, we develop the matrix algebra necessary to implement the model for real tables. We show how to measure the benefits associated with technological progress as well as their distribution between the innovative sector, up and downstream intermediate sectors and final users. In this respect, the structural change that the innovation brings into the economy (i.e. changes in the technical and primary inputs coefficients) can be studied from different perspectives. As final demand is normally treated as exogenous, the resources released by the innovation affect final deliveries depending on how they are reassigned, this leads to either the expansion or contraction of any given sector across different regions. In addition, whether the innovation ultimately results in higher profits, lower prices or a combination of the two depends on the market structure and alternative assumptions referring to market power when setting prices. Prices can then be treated as dependent variables at the sector-specific level; either as variable or fixed. In this research, we assess the effects of the innovation under these settings.

[1] An authoritative discussion of meaningful decompositions of total factor productivity indices is presented by Balk and Zofío (2018), along with its accompanying toolbox, Balk et al. (2020). For a recent contribution on the dual and primal approaches to productivity measurement, see Grifell-Tatjé and Lovell (2021).

Recent literature on the economy-wide effects of innovations relying on regional IO analysis shows that this is a research topic of increasing interest among academics. Relevant examples are Roson and Sartori (2016), who study whether relatively small productivity shocks could lead to sizable macroeconomic variability. They find that the variability of GDP, induced by sectoral shocks, is basically determined by the degree of industrial concentration in terms of value-added. Jiang et al. (2018) use intermediate input shares as a proxy of technology, to analyse the pattern of regional technology distributions across manufacturing sectors in China, as well as the extent of interregional technology spillovers. These authors reveal, as we do, that there is great variability in the magnitude of effects across regions, with interregional backward spillovers having significantly positive impacts in China's eastern (coastal) regions. By contrast, the vertical spillovers of the central and western regions are largely dominated by an intra-regional forward effect. The present paper contributes to the growing body of research. In contrast to prior studies, and as previously stated, we develop and implement Carter's (1990) methodological framework, which operates through changes in the technical coefficients. This requires deriving the tools necessary for assessing the upstream and downstream benefits of innovations in the form of productivity gains.

As innovation case, we focus on freight road transportation and study the adoption of longer and heavier duty vehicles (LHVs, also known as 'road trains' or 'megatrucks'), which almost double the payload capacity of the currently predominant 40-ton articulated truck. In the existing literature, assessments of the potential benefits of introducing LHVs are mainly based on theoretical simulations that use cost/benefit analysis (CBA) – see De Ceuster et al. (2008); Doll et al. (2009); Eidhammer et al. (2009); Ericson et al. (2010); Kindt et al. (2011); Knight et al. (2008); Lukason et al. (2011); McKinnon (2005); Ortega et al. (2014). An exception is the study by Guzman et al. (2016) who also examine the economic impact of introducing LHVs in Spain using the IO framework. Rather than evaluating economy-wide benefits that rely on Carter's (1990) approach, however, their model is based upon a random utility-based assumption. Simulations on the effects of adopting LHVs with their model begin with the estimation of a new interregional 'trade' matrix predicting the changes in freight flows. These changes are based on the probability that a product of a sector destined to be consumed in one region is transported either from a different region or the region itself. Therefore, in the LHVs scenario, their model focuses on substitution effects. Cost reductions change the trade relationship among regions, the regional production trends and, consequently, the road freight flows over the transportation network. Most importantly, as transport costs are a component of final prices, Guzman et al. assume that their reduction necessarily results in lower prices; this leads to increases in real GDP and employment.

Our study qualifies the findings of Guzman et al. by focusing on the measurement of the sector-specific productivity gains caused by the introduction of LHVs and their effect on the different components of real GVA – and not only on the GDP aggregate. Subsequently, we determine how these gains are distributed within the economy through detailed – sectoral and regional – backward and forward linkages. Also, we can conclude that, given the expected change in the market structure of the LHVs sector, firms operating these vehicles appropriate most of the productivity gains in the form of greater operating surplus via increased market concentration. In this scenario, cost reductions may not completely benefit consumers as in Guzman et al. (2016), as they can also enhance the margins of (large) firms operating in the LHVs market.

Road freight transportation is a key sector in the functioning of the EU single-market. In 2017, it accounted for 76.7% of all goods movements in the European Union, and its share is consistently growing (i.e. from 74.8% in 2013). Also, in terms of ton-kilometres (hereafter, ton × km), road freight transportation increased by 11.8% from 2013 to 2017, see Eurostat (2019). Overall, given its unchallenged relevance in freight transportation, the adoption of LHVs is being evaluated by the European Commission as a way of enhancing the productivity of the transportation sector, while reducing the social costs associated with externalities such as pollution, noise and accidents (see Christidis and Leduc (2005) and previous references for an early assessment of these environmental effects). In the case of Spain, this study is motivated by the interest of the Spanish Ministry of Transportation (*Ministerio de Fomento*, MFOM) in assessing the effects of this innovation both at the aggregate national level and for the economies of individual regions.

From an empirical perspective, and in line with the previous references, we illustrate the specific transport innovation through the substitution of an articulated road haulage megatruck, measuring up to 25.25 meters and with a maximum authorized mass (MAM) of 60-ton, for the standard 40-ton truck. The cost structure of both configurations is compared through a detailed study based on engineering parameters, thereby allowing us to calculate the operational cost savings. The latter savings are subsequently transferred to the transportation cost matrix embedded in the IO table according to the European System of Accounts 1995, ESA95 (Eurostat, 1996). We implement our approach using a recently compiled regional IO table that disaggregates the transportation sector by modes (road, rail, air, and sea), differentiating each mode in terms of goods and passengers. Henceforth, we refer to this Transportation oriented Interregional Input–Output table as 'TIRIO'. Regarding the underlying Spanish interregional IO tables, their background data and calculations methods *à la* Isard (1951), can be consulted in detail in Pérez (2001), and Pérez et al. (2009). Llano (2004, 2009) uses these tables to analyse the spillover effects derived from trade relationships, while Llano et al. (2010) analyse the trade flows from the C-intereg database. The TIRIO we use here is a set of accounts from 2008.[2]

The paper unfolds as follows. In Section 2 we present the research approach that implements Carter's (1990) model, albeit with a real regional IO table. We then introduce innovations in the form of lower technical coefficients to the Leontief production function. We then describe the demand model that allows quantifying the interregional trade flows (backward and forward effects) within the economic system in terms of the reference macro magnitudes: production, intermediate consumptions, gross value added (GVA) and its components. We also present the equivalent price model. Finally, we introduce the expressions necessary to analyse the effects of the innovation in terms of changes in the demand and price models. We also discuss how to account for different market structures

[2] The design and identification of the necessary information to estimate the TIRIO was led by the L. R. Klein Institute, Universidad Autónoma de Madrid (Spain), together with the current authors and other researchers involved in the DESTINO project, financed by the Spanish Ministry of Transportation, with the present study fulfilling the research objectives related to the measurement of the economy wide benefits of introducing LHVs based on Carter's method. Ancillary studies by other members of the project that are recalled in this research are cited throughout the text; e.g. the engineering studies on the adoption of LHVs by Ortega et al. (2011, 2014).

in the transportation sector where innovation takes places, by differentiating between flex- or fix-price sectors.

In Section 3 we describe how we operationalise the adoption of the megatruck as the innovation of interest. Here we calculate productivity gains in freight road transportation resulting from lower operational costs. We follow the analytical structure of previous studies that calculate generalized transportation costs in road freight shipping and differentiate between time and distance economic costs when determining the savings related to the adoption of the megatruck. Mapping the savings that correspond to each individual input of the transportation production function into their counterpart sectors within the National Accounts is critical for correctly assessing the economic impacts of innovation. The process also involves expressing operating costs at producer prices (as recorded in firms' private account balances) in terms of basic prices (as national accountancy conventions dictate). Section 4 incorporates the savings estimated into the TIRIO structure. Here we calculate the weights matrix corresponding to the new technical coefficients associated with innovation, which characterize the new table.

Section 5 presents the results corresponding to the measurement of productivity gains in terms of increases in gross operating surplus/mixed income and/or reductions in prices. We also present the accompanying effects within the IO system in terms of parallel changes in the most relevant macro magnitudes. Obtaining the results for each one of the models represents the final stage of the analysis. Finally, in Section 6, we summarize our approach, the specific simulation for the transportation sector, and the main findings and conclusions.

2. Bringing innovations to IO models through the Leontief production function

Analyses of the economy-wide effects of innovation via changes in IO production structures can be found as early as Blair and Wyckoff (1989) and Fontela and Pulido (1991). Carter (1990) was the first author to propose simulating these effects by way of changes in the technical coefficients. Subsequently, following this approach, Prieto and Zofío (2007) evaluated productive efficiency in terms of activity analysis (i.e. data envelopment analysis) with respect to a best technological practice (or benchmark frontier defined by the observations with the most efficient combinations of technical coefficients). An extensive bibliography of alternatives for simulating changes in technology can be found in Pulido and Fontela (1993, Chap. 4) and Miller and Blair (2009, Chap. 7).

Carter (1990) does not explicitly refer to the Leontief production function as the starting point to model innovations in the form of lower technical coefficients. In this regard, we follow Zofío and Prieto (2007), who established said connection based on production theory. In our current multiregional setting, we define a compact production function for each region, $r = 1, \ldots, R$, which includes the inputs and outputs that each of the, $s = 1, \ldots, S$, sector uses/produces. In this way, it is possible to differentiate the intraregional/interregional effects that each region r has domestically, and on the remaining $R-1$ regions.

In the context of the analytical construction of Leontief, the output of a given sector j in region r can be denoted as x_j^r, thus enabling us to compactly write its production function as[3]

$$x_j^r = \boldsymbol{f}(z_{sj}^{rr}, z_{sj}^{kr}, z_{sj}^{mr}, tpos_j^r, v_{j,g}^r), r, k = 1, \ldots, R; s, j = 1, \ldots, S; g = l, c, t; R = 19, S = 35. \tag{1}$$

where z_{sj}^{rr}, z_{sj}^{kr}, and z_{sj}^{mr} represent intraregional, interregional and imported trade flows, respectively. Specifically, z_{sj}^{rr} denotes the trade flows from sector s located in region r to our reference sector j also located in region r (i.e. intraregional trade, also called internal or domestic transactions); z_{sj}^{kr} captures the trade flows from sector s in region k to sector j in region r (interregional flows); while z_{sj}^{mr} captures the trade flows incoming from the rest of the world (m), i.e. imports. In addition, $tpos_j^r$ represents taxes, less subsidies received, on products associated with z. Finally, $v_{j,g}^r$ refers to gross value added (GVA) including the following g components: l, compensation of employees, c, gross operating surplus/mixed income, and t, other taxes, less subsidies, on production.

Dividing by x_j^r, (1) is expressed in *per* unit of output or, equivalently, in terms of technical coefficients:

$$1_j^r = f\left(\frac{z_{sj}^{rr}}{x_j^r}, \frac{z_{sj}^{kr}}{x_j^r}, \frac{z_{sj}^{mr}}{x_j^r}, \frac{v_{j,g}^r}{x_j^r}, \frac{tpos_j^r}{x_j^r}\right) = f(a_{sj}^{rr}, a_{sj}^{kr}, a_{sj}^{mr}, \bar{v}_{j,g}^r, \overline{tpos}_j^r). \tag{2}$$

The domestic technical coefficients for trade: a_{sj}^{rr}, a_{sj}^{kr} form the square matrix $\mathbf{A}^d$, which is partitioned into sub-matrices $\mathbf{A}^{rr}$ and $\mathbf{A}^{kr}$, containing the trade flows between k and r (if $k = r$, then we have the intraregional (domestic) trade flows in the diagonal of $\mathbf{A}^d$):

$$\mathbf{A}^d = \begin{pmatrix} \mathbf{A}^{11}\mathbf{A}^{12} \ldots\ldots\ldots\ldots \mathbf{A}^{1R} \\ \mathbf{A}^{21} \ldots\ldots\ldots\ldots\ldots \mathbf{A}^{2R} \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ \mathbf{A}^{R1}\mathbf{A}^{R2} \ldots\ldots\ldots\ldots \mathbf{A}^{RR} \end{pmatrix}. \tag{3}$$

The matrix $\mathbf{A}^d$ constitutes the basic element behind the calculations of the effects of IO simulations. In IO models, including our TIRIO, this matrix captures the existing technologies, the transportation innovations considered here being implemented through changes to these technical coefficients (as presented below in Section 4, Table 6).

Also, we can define matrix $\mathbf{A}^m$ to include the technical coefficients of imports from the rest of the world, a_{sj}^{mr}:

$$\mathbf{A}^m = (\mathbf{A}^{m1}\mathbf{A}^{m2} \ldots\ldots\ldots\ldots \mathbf{A}^{mR}).$$

2.1. Demand model

Based on matrix A^d above, the different terms comprised in final domestic demand, F^d, can be expressed in compact form as

$$\mathbf{F}^d = (\mathbf{I} - \mathbf{A}^d)\mathbf{X}. \tag{4}$$

[3] Notation: double subscripts and superscripts denote origins and destinations between sectors and regions, respectively; upper-case boldface font denotes matrices; lower-case boldface font denotes vectors; and lowercase italics denote elements or variables. The general characteristics of the Leontief model can be consulted in Miller and Blair (2009).

From (4) we obtain the answer to the classic problem of what production of each sector is necessary to fulfil a given level of final demand; i.e.

$$\mathbf{X} = (\mathbf{I} - \mathbf{A}^d)^{-1}\mathbf{F}^d = \mathbf{L}\mathbf{F}^d.$$

In the TIRIO context, a generic element of $\mathbf{L}$, α_{sj}^{kr}, indicates the necessary increment in production in sector s in region k, for each unit increment in the final demand of sector j in r, $\Delta\mathbf{F}_j^r$ (i.e. in the same magnitude or measurement unit in which the table is expressed).

2.1.1. Backward and forward effects in the TIRIO

In this section, we present the algebra required in order to measure the overall economic importance of the transportation sector in the different regions as well as to the specific road freight transportation sector we study. This helps to show the relevance of the sector in which our case of innovation is framed. This is achieved by running two spillover simulations corresponding to backward and forward effects. Although the results of these simulations are exhibited in Section 5, here we present the analytical framework for the purpose of methodological consistency.

The quantification of innovation effects is developed through a matrix of impact effects in the face of exogenous variations in aggregated final domestic demand. This process permits the measurement of the spillover effects on macro-magnitudes: production, intermediate consumptions, gross value added (GVA) and its components, gross operational surplus/mixed income (GOP/MI), etc., from a dual perspective: i.e. backward effects (what each sector requires or demands from upstream sectors and regions) and forward effects (what the sector generates in downstream sectors and regions). Specifically, the backward capacity (also referred to in the literature as supply multiplier) measures the effect that an increment in final demand in a given sector j in region r would have in one, some, or all of the upstream sectors belonging to one or several regions of the national economy: $\Delta\mathbf{F}_j^r$. This effect quantifies what are the sector(s) need(s) from the economy (output multipliers resulting in upstream effects induced through the backward linkages).[4] On the contrary, the forward capacity (also referred to as demand multiplier), measures what the economic effects are in downstream sectors and regions, when the increment in final demand disperses throughout the economic system: $\Delta\mathbf{F}_S^R$. This latter effect can be seen as the result of an increase in demand in a given sector (or set of sectors) of a specific region (i.e. the initial backward effect $\Delta\mathbf{F}_j^r$, so the forward effect is the consequence of that initial change). For both effects, if a specific region r is removed from the calculations of the overall TIRIO subtracting its associated changes, we obtain the spillover between regions as a net effect, while removing the remaining $R-1$ effects ($k \neq r$) yields internal or domestic effects.

To obtain the alternative trade flows derived from an exogenous shock to final demand, and the backward and forward effects, for regions r and k, respectively, through (1), (2) and (3), we rely on the following matrices:

$$\mathbf{A}^{rr} = \mathbf{Z}^{rr}(\hat{\mathbf{X}}^r)^{-1}; \mathbf{A}^{rk} = \mathbf{Z}^{rk}(\hat{\mathbf{X}}^k)^{-1}; \mathbf{A}^{kr} = \mathbf{Z}^{kr}(\hat{\mathbf{X}}^r)^{-1}, \forall r \neq k,$$

[4] Another way to quantify the backward capacity is the regional extraction method, introduced by Miller (1966, 1969); see Llano (2009) for applications in the Spanish regional IOT. Additionally, it is possible to isolate the region from the system and to calculate the weight of a region through the overall percentage error measure (OPE), as suggested by Miller and Blair (2009, p. 84 and chapter 3).

where $\hat{\mathbf{X}}$ is the diagonalized matrix of the output vector, and the trade flows can be calculated based on (4) as

$$\mathbf{F}^r = (\mathbf{I} - \mathbf{A}^{rr})\mathbf{X}^r - \mathbf{A}^{rk}\mathbf{X}^k, \tag{5}$$

$$\mathbf{F}^k = (\mathbf{I} - \mathbf{A}^{kk})\mathbf{X}^k - \mathbf{A}^{kr}\mathbf{X}^r, \tag{6}$$

which, solving for $\mathbf{X}^r$ and $\mathbf{X}^k$, leads to

$$\mathbf{X}^r = (\mathbf{I} - \mathbf{A}^{rr})^{-1}(\mathbf{A}^{rk}\mathbf{X}^k + \mathbf{F}^r), \tag{7}$$

$$\mathbf{X}^k = (\mathbf{I} - \mathbf{A}^{kk})^{-1}(\mathbf{A}^{kr}\mathbf{X}^r + \mathbf{F}^k). \tag{8}$$

If we consider the sequence of impacts originating from an increment in the final demand of region r: $\Delta\mathbf{F}^r \to \Delta\mathbf{X}^r \rightleftarrows \Delta\mathbf{X}^k$, it is possible to obtain, in terms of the increment, the impact on r and k.

If we assume that increments in the final demand in k are null when analysing the effect of r on k, and vice versa; i.e. $\Delta\mathbf{F}^r, \forall\Delta\mathbf{F}^k = 0$ and $\Delta\mathbf{F}^k$, $\forall\Delta\mathbf{F}^r = 0$, and substituting (8) in (5) and (7) in (6), we obtain:

$$\Delta\mathbf{F}^r = (\mathbf{I} - \mathbf{A}^{rr})\Delta\mathbf{X}^r - \mathbf{A}^{rk}(\mathbf{I} - \mathbf{A}^{kk})^{-1}\mathbf{A}^{kr}\Delta\mathbf{X}^r, \Delta\mathbf{F}^k = 0, \tag{9}$$

$$\Delta\mathbf{F}^k = (\mathbf{I} - \mathbf{A}^{kk})\Delta\mathbf{X}^k - \mathbf{A}^{kr}(\mathbf{I} - \mathbf{A}^{rr})^{-1}\mathbf{A}^{rk}\Delta\mathbf{X}^k, \Delta\mathbf{F}^r = 0, \tag{10}$$

which allow the evaluation of the impacts on regions r and k of changes in the final demand of k and r, in each (or all) of their sectors. Referring to (9), the term

$$\mathbf{A}^{kr}\Delta\mathbf{X}^r \tag{11}$$

shows the direct (backward induced) *flow of trade* from k to r, resulting from the increase of production in r; while

$$(\mathbf{I} - \mathbf{A}^{kk})^{-1}\mathbf{A}^{kr}\Delta\mathbf{X}^r \tag{12}$$

captures the *spillover* effect of the direct and indirect production needs in k.

Completing the sequence of impacts, the additional recursive flow from r to k that maintains the increment in production in k associated with the original spillover effect (12), corresponds to *feedback* trade flows:

$$\mathbf{A}^{rk}(\mathbf{I} - \mathbf{A}^{kk})^{-1}\mathbf{A}^{kr}\Delta\mathbf{X}^r. \tag{13}$$

These formulae enable the analysis of the interdependency between r and k due to$\Delta\mathbf{F}^r$, in a consistent and structured way as presented in Table 1, showing the flows of trade.

We devote the first part of Section 5 which presents the results of the study to illustrate the relevance of the transportation sector in the Spanish economy in terms of the different backward and forward effects (trade flows), taking into consideration the systematic characterization presented in Table 1. Also, Appendix A details the matrix algebra capturing these trade interrelationships in an IO table with R regions, where K is the remaining block of $R-1$ regions different from r.

Table 1. Trade flows between r and K ($R-1$ regions) due to ΔF^r.

		Trade flows			Net effect	Total effect
$\Delta \mathbf{F}^r$	K	Spillover **(4)**	Feedback (2)	Exports to r (3)	(4)−(2)+(3)	(1)+(2)−(3)+(4)−(2)+(3) = **(1)+(4)**
	r	Domestic **(1)**		Imports from K (3)	(1)+(2)−(3)	

Source: Own elaboration.

2.2. Price model

From a methodological perspective, we also explore the price effects of the TIRIO, both before and after implementing the innovation represented by the adoption of the mega-truck. In this case, innovations can eventually lead to lower prices within the economic system. As with the demand model, before we introduce the methods to assess the price effects after innovation, we present the price model for the TIRIO. We depart from the production function (1), which allows expressing production from the input (resource) side as follows:

$$x_j^r = \sum_{k=1}^{K}\sum_{s=1}^{S} z_{sj}^{kr} + \sum_{s=1}^{S} z_{sj}^{mr} + v_{j,l}^r + v_{j,c}^r + v_{j,t}^r + tpos_j^r.$$

If we multiply the quantity of a product j by its domestic production price, p_j^r, and by the price of the rest of regions, p_s^r, $k \neq r$, and the rest of the world, p_s^m, the above expression is transformed, assuming unit value-added prices, into:

$$x_j^r p_j^r = \sum_{k=1}^{K}\sum_{s=1}^{S} z_{sj}^{kr} p_s^k + \sum_{s=1}^{S} z_{sj}^{mr} p_s^m + v_{j,l}^r + v_{j,c}^r + v_{j,t}^r + tpos_j^r.$$

The corresponding price model expressed in terms of technical coefficients is

$$p_j^r = \sum_{k=1}^{K}\sum_{s=1}^{S} a_{sj}^{kr} p_s^k + \sum_{s=1}^{S} a_{sj}^{mr} p_s^m + \bar{v}_{j,l}^r + \bar{v}_{j,c}^r + \bar{v}_{j,t}^r + \overline{tpos}_j^r, \tag{14}$$

and generalizing (14) for all sectors S and regions R yields:

$$\mathbf{p}^d = (\mathbf{I} - \mathbf{A}^{d'})^{-1}(\mathbf{A}^{m'}\mathbf{p}^m + \bar{\mathbf{v}}_l + \bar{\mathbf{v}}_c + \bar{\mathbf{v}}_t + \overline{\mathbf{tpos}}). \tag{15}$$

Equations 14 and 15 measure the effects of variations on some, or all, of the terms: intermediate and primary inputs, taxes less subsidies on the products, and import prices.[5] We resort to the price model to assess to what extent the technological advantages of innovation may be transferred to downstream economic agents in the form of lower prices.

2.3. Calculating the effects of innovation

We now present the methods necessary to evaluate the economy-wide effects of innovation. From the cost perspective linked to the production process, innovation in the transportation sector in region r involves a change in technical coefficients. Let us denote by TIRIO$^{\mathbf{\Omega}}$

[5] We consider p^m as a unit vector exogenous to the model.

the IO table including the new matrix of domestic technical coefficients, whose calculation through a weight matrix $\mathbf{\Omega}$ is discussed in Section 4. Then, from the TIRIO$^{\mathbf{\Omega}}$, we obtain the technical coefficient structure associated with innovation. Departing from the TIRIO$^{\mathbf{\Omega}}$, we can express the unit production function (2) in the following way:

$$1-\delta_j^r = f\left(\frac{\underline{z}_{sj}^{rr}}{x_j^r}, \frac{\underline{z}_{sj}^{kr}}{x_j^r}, \frac{\underline{z}_{sj}^{mr}}{x_j^r}, \frac{\underline{v}_{j,g}^{r}}{x_j^r}, \frac{\underline{tpos}_j^{r}}{x_j^r}\right) = f(\underline{a}_{sj}^{rr}, \underline{a}_{sj}^{kr}, \underline{a}_{sj}^{mr}, \underline{v}_{j,g}^{r}, \underline{tpos}_j^{r}),\ g = l, c, t, \tag{16}$$

where δ_j^r is the gain in productivity of r, j derived from innovation, and where underlined variables (e.g. $\underline{a}_{sj}^{rr}, \underline{a}_{sj}^{kr}$, etc.) denote the new technical coefficients, which are therefore substituted in the production function.

2.3.1. Calculating the effects of innovation with the demand model: TIRIO$^{\Omega}$

The matrix of technical coefficients of domestic intermediate consumption after innovation, $\underline{\mathbf{A}}^d$:$\underline{a}_{sj}^{rr}$,$\underline{a}_{sj}^{kr}$, yields the Leontief inverse: $\underline{\mathbf{L}}$. In this way, the change in technical coefficients may lead to a change in production in all sectors for a single final demand:[6]

$$\underline{\mathbf{X}} = \underline{\mathbf{L}}\mathbf{F}^d. \tag{17}$$

The reduction of the technical coefficients in an innovative region r yields a gain in productivity, $\delta_j^r \in \boldsymbol{\delta}$, so

$$\boldsymbol{\delta}' = \mathbf{i}' - \mathbf{i}'\underline{\mathbf{A}}^d - \mathbf{i}'\underline{\mathbf{A}}^m - \underline{\mathbf{v}}_l' - \underline{\mathbf{v}}_c' - \underline{\mathbf{v}}_t' - \underline{\mathbf{tpos}}', \tag{18}$$

which, in absolute value, is

$$\Delta = \hat{\boldsymbol{\delta}}\underline{\mathbf{X}}.$$

Thus, for example, given our focus on the effects of innovation on profits, corresponding to larger gross operating surplus/mixed income, GOS/MI, (i.e. the dual counterpart of the productivity gains), this value can be calculated according to the expression

$$\underline{\underline{\mathbf{v}_c}}' = \underline{\mathbf{X}}' - \mathbf{i}'\underline{\mathbf{Z}}^d - \mathbf{i}'\underline{\mathbf{Z}}^m - \underline{\mathbf{tpos}}' - \underline{\mathbf{v}}_l' - \underline{\mathbf{v}}_t' = \underline{\mathbf{v}}_c' + \Delta', \tag{19}$$

whose vector of technical coefficients is

$$\underline{\underline{\mathbf{v}}}_c = \underline{\mathbf{v}}_c + \boldsymbol{\delta}. \tag{20}$$

2.3.2. Calculating the effects of innovation on prices with the price model

As previously anticipated, the cost savings associated with innovation may lead to price reductions. In that case, the prices in region r for the road freight transportation sector, which in our TIRIO corresponds to sector 25 ($S25$), will be

$$\underline{p}_{25}^r = 1 - \delta_{25}^r. \tag{21}$$

In a somehow counterintuitive denomination, Carter (1990, p. 243) named as *fix-price* sectors those innovative sectors that pass cost savings on to the rest of the economy by lowering

[6] Alternatively, we could maintain production and obtain the new final demand: $\underline{\mathbf{F}}^d = (\mathbf{I} - \underline{\mathbf{A}})\mathbf{X}$.

their own prices, implying that their gross operating surplus (profit) remains unchanged because costs and revenues decrease simultaneously in equivalent amounts. Subsequently, this reduction in intermediate prices benefits other sectors and regions buying from $S25$ located in r (spillover effects), which, in turn, may see their profits increase as long as they can keep their own prices rigid. If they also reduce their prices, the benefits eventually reach final demand, because they are not appropriated by the innovative or downstream sectors but are distributed throughout the economy. On the contrary, if the innovative sector does not pass on the benefits of innovation in the form of lower prices but keeps the initial prices p_{25}^r rigid, it is deemed as a *flex-price* sector in Carter's terminology, and it appropriates the innovation completely in the form of higher profits. Whether a sector is *fix-* or *flex-*, with prices either decreasing or remaining constant, depends on the actual degree of competition in the innovative sector. If competition is effective, the cost-saving will be passed on to the economy. If market power is high, as is the case of the LHVs market niche in Spain (as commented in the empirical section), then prices will be unaffected with firms appropriating the cost reduction with a resulting increase in profits.

Therefore, different scenarios can be hypothesized for the price trends in the overall economy. Considering the above example, with fix-price sectors exhibiting a general reduction in production prices in sectors and regions where the innovation does not take place, thanks to lower costs in the intermediate inputs from $S25$, the resulting change in prices given the new TIRIO$^{\boldsymbol{\Omega}}$ can be ascertained by solving the following equation:

$$\underline{\mathbf{p}}^d = (\mathbf{I} - \underline{\mathbf{A}}^{d\prime})^{-1}(\underline{\mathbf{A}}^{m\prime}\mathbf{p}^m + \underline{\mathbf{v}}_l + \underline{\mathbf{v}}_c + \underline{\mathbf{v}}_t + \underline{\mathbf{tpos}}). \tag{22}$$

A second assumption is to maintain constant (unit) prices in the remaining regions and sectors (thereby, considered as flex-price sectors), transferring their reduction to the gross operating surplus/mixed income, $\underline{v}_{j,c}^k$, according to the following equation:

$$\underline{v}_{j,c}^k = 1 - \sum_{s=1}^{S} a_{sj}^{kk} p_s^k - \sum_{s=1}^{S} a_{sj}^{mk} p_s^m - \sum_{r=1}^{R} \sum_{\substack{s=1 \\ \left(\substack{s \neq 25 \\ if\ k=r}\right)}}^{S} a_{sj}^{rk} p_s^r - a_{25j}^{rk} \underline{p}_{25}^r - \bar{v}_{j,l}^k - \bar{v}_{j,t}^k - \overline{tpos}_j^k, \tag{23}$$

where the j sectors located in r regions, different from those where the innovation takes place ($k = r, j \neq 25$), can benefit from lower prices.

It is also possible to establish intermediate hypotheses between the extreme case assigning all of the productivity gains to the gross operating surplus/mixed income (profits) in $S25$, or assigning them to reducing prices across the economy. Hence, we can define a vector of distribution coefficients, $\alpha_j^r \in \boldsymbol{\alpha}$ between both magnitudes calculating prices for the entire system. Then, Equations (21), (20) and (22) become, respectively:

$$\begin{gathered}
\underline{\underline{\underline{p}}}_{25}^r = 1 - (1 - \alpha_{25}^r)\delta_{25}^r, \\
\underline{\underline{\underline{\mathbf{v}_c}}} = \underline{\mathbf{v}}_c + \hat{\boldsymbol{\alpha}}\boldsymbol{\delta}, \text{ and} \\
\underline{\underline{\underline{\mathbf{p}}}}^d = (\mathbf{I} - \underline{\mathbf{A}}^{d\prime})^{-1}(\underline{\mathbf{A}}^{\prime m}\mathbf{p}^m + \underline{\mathbf{v}}_l + \underline{\underline{\underline{\mathbf{v}_c}}} + \underline{\mathbf{v}}_t + \underline{\mathbf{tpos}}).
\end{gathered} \tag{24}$$

2.3.3. Flexible/fix-price model

As discussed above, in this model we consider the market structure characterizing the innovative sector, which, following Carter (1990), relates to the capability of firms to appropriate innovation in the form of higher profits through price setting (i.e. mark-up settings above production costs) versus the competitive result by which cost reductions are passed on to downstream consumers in the form of lower prices (i.e. at the limit competitive prices equal production costs). This trade-off is configured in the TIRIO through a structure of variable or rigid prices. Firms operating in the innovative sector j in region r, characterized by a low degree of competition, are capable of allocating the productivity gains to the gross operating surplus/mixed income (GOS/MI), while sectors with a high degree of competition allocate it to price reductions. Due to trade, firms operating in non-competitive sectors benefit from the lower prices in sectors with price reductions, additionally increasing their GOS/MI.

Based on these considerations, we divide matrix $\mathbf{A}$ into two blocks: $\mathbf{A}^{Flex}$, with inter-industrial relationships of j in r (flexible); and $\mathbf{A}^{Fix}$, the remaining sectors and regions. For each block, we define the corresponding partitioned vectors of GVA coefficients: $(\bar{\mathbf{v}}_g^{Flex}, \bar{\mathbf{v}}_g^{Fix}), g = l, c, t$; taxes less subsidies on products: $(\overline{\mathbf{tpos}}^{Flex}, \overline{\mathbf{tpos}}^{Fix})$, and intermediate demand imported from the rest of the world, matrices $\mathbf{A}^{mFlex}$ and $\mathbf{A}^{mFix}$, with a unit price vector $\mathbf{p}^m$ (exogenous).

The partitioned vector of domestic production prices, $(\mathbf{p}^{Flex}, \mathbf{p}^{Fix})$, can be expressed in a generalized manner, in the following matrix form:

$$
\begin{aligned}
(\mathbf{p}'^{Flex}, \mathbf{p}'^{Rig}) & \begin{bmatrix} \mathbf{I} - \mathbf{A}^{FlexFlex} & -\mathbf{A}^{FlexFix} \\ -\mathbf{A}^{FixFlex} & \mathbf{I} - \mathbf{A}^{FixFix} \end{bmatrix} = \\
&= \mathbf{p}'^{m}(\mathbf{A}^{mFlex}, \mathbf{A}^{mFix}) + (\bar{\mathbf{v}}_l'^{Flex}, \bar{\mathbf{v}}_l'^{Fix}) + (\bar{\mathbf{v}}_c'^{Flex}, \bar{\mathbf{v}}_c'^{Fix}) + \\
&\quad + (\bar{\mathbf{v}}_t'^{Flex}, \bar{\mathbf{v}}_t'^{Fix}) + (\overline{\mathbf{tpos}}'^{Flex}, \overline{\mathbf{tpos}}'^{Fix}).
\end{aligned}
$$

In this diagram, by introducing an innovation to the *Flex* sector and with at least one *Fix* sector, it is transmitted through price reductions in fix-price sectors and a rising surplus in flex-price sectors:

$$
\underline{\mathbf{p}}'^{Fix} = (\mathbf{p}'^{Flex}\underline{\mathbf{A}}^{FlexFix} + \mathbf{p}'^{mFix}\underline{\mathbf{A}}^{mFix} + \underline{\mathbf{v}}_l'^{Fix} + \underline{\mathbf{v}}_c'^{Fix} + \underline{\mathbf{v}}_t'^{Fix} + \underline{\mathbf{tpos}}'^{Fix})(\mathbf{I} - \underline{A}^{FixFix})^{-1} \tag{25}
$$

$$
\underline{\mathbf{v}}_c'^{Flex} = \mathbf{p}'^{Flex}(\mathbf{I} - \underline{\mathbf{A}}^{FlexFlex}) - \underline{\mathbf{p}}'^{Fix}\underline{\mathbf{A}}^{FixFlex} - \mathbf{p}'^{mFlex}\underline{\mathbf{A}}^{mFlex} - \underline{\mathbf{v}}_l'^{Flex} - \underline{\mathbf{v}}_t'^{Flex} - \underline{\mathbf{tpos}}'^{Flex} \tag{26}
$$

In (25) and (26), the *Flex* price remains unchanged. Thus, we observe that the innovation reflected in the technical coefficients of a sector with flexible prices would leave prices constant ($\mathbf{p}^{Flex}$) and allow for increases in surplus ($\underline{\mathbf{v}}_c^{Flex}$). In addition, modification of the *Fix* sectors has no effect on the surplus of these sectors ($\bar{\mathbf{v}}^{Fix}$), and translates itself into a reduction in production prices ($\mathbf{p}^{Fix}$), giving way, through (25) to new increments of the surplus in *Flex* sectors, (26).

In Section 5 we present the results of innovation associated with the adoption of the megatruck in the transportation sector. We extensively use Equations (24), (25) and (26) to determine its economy-wide effects in the form of changes for all relevant macro-magnitudes.

3. Innovation in the sector of road freight transportation: the 'megatruck'

In this section, we compare the innovation resulting from the substitution of the current technological structure (coefficients) corresponding to the standard articulated heavy-duty vehicle (HDV) – the current workhorse of road freight transportation in Europe, with that associated with a technological target characterized by a longer and heavier vehicle ('road train' or 'megatruck').[7] Here we calculate the new operating costs corresponding to the innovation. We essentially replace the existing technical coefficients matrix with a new one, which results from innovation by applying a set of weights. The calculated result of this switch is presented in Section 4 to obtain a modified IO table, denoted previously by $\mathrm{TIRIO}^{\boldsymbol{\Omega}}$. Our starting point is the current structure of annual economic costs associated with the HDV from which we depart to show how these costs are reduced through the adoption of the megatruck.

3.1. The innovation: characteristics of the 'megatruck'

Relying on the engineering approach, we compare the operating cost structure of the current 40-ton articulated truck to that of a representative megatruck.[8] This comparison is made in terms of time costs (€/hour), distance costs (€/km), plus indirect costs, which are calculated as a percentage of the previous two. In both configurations, fuel and salaries account for the largest shares of total operating costs. For the current HDV configuration, they represent about 30% and 25%, respectively (see Zofío et al., 2014).[9] Table 2 shows the structure of operating costs and their breakdown by components.

We now present the characteristics of the innovation associated with the adoption of the megatruck as the largest authorized transportation vehicle. First, it is necessary to choose the type of megatruck that can be used as a reference for the calculation of the new cost structure. Among all the options considered by Debauche and Decock (2007), the MST_{23} model is selected as the representative megatruck given its versatility and road infrastructure characteristics in Spain. The configuration consists of a tractor unit combined with a semi-trailer (i.e. the standard HDV), to which a two-axle trailer is added. It is a seven-axle articulated vehicle of 480 hp with a MAM of 60 tons and a payload of 40 tons (versus 455 hp, 40-ton MAM and 25-ton payload of the current HDV). The structure of our 'megatruck-type' is shown in Figure 1.

[7] Over 85% of all goods shipments in Spain is by road (MFOM, 2016), while out of this percentage, 80% is performed with the standard HDV, MFOM (2019).

[8] Only operational (private) costs are considered. In contrast, Ortega et al. (2011), whose content is partially published as Ortega et al. (2014) and Guzman et al. (2016), emphasize the complexity of innovation, which involves more than changes in productive processes, scalable to the conservation of roads, investment in capital, accident rates, pollution, etc. (externalities), or to management (new logistics organization, capacity of use, etc.) and/or to the consumer (new products, their mixture, preferences, etc.).

[9] As in Zofío et al. (2014), this analysis of the operating costs of transportation has been applied to the calculation of generalized transportation costs, GTCs. GTCs measure the economic cost of shipping one reference vehicle (i.e. the standard HDV) between two locations considering the economic costs associated with distance and time, the road infrastructure, type of operator and legal regulations (i.e. speed limits, mandatory stops, etc.). Combining these factors, it is possible to determine the optimal route as the solution of the GTCs, see Persyn et al. (2020) for a recent application of this methodology to all EU regions.

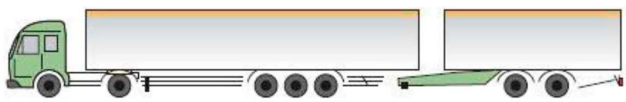
Table 2. Operating costs of road freight transportation by components.

DIRECT Costs (DC_{ij})			INDIRECT Costs (IC_{ij})
FIXED Costs (*Time*)		VARIABLE Costs (Distance)	
Capital:	Operating:	Fuel	Administration overheads:
Amortization	Labour	Tires	Administrative staff
Financing	Insurance	Maintenance and repairs	Outsourced activities
	Taxes	Accommodation and allow.	Marketing, etc.
		Tolls	

Parameters current HDV: Operation: 120,000 km/year (102,000 km freighted and 18,000 km empty).
Activity: Working time: 1,906 h/year; in load 1,620; 8.5 h/day; activity ratio 225 days.
Technical: Engine power: 455 hp; MAM 40-ton; 5 axes; 12 tires; payload 25-ton.
Parameters Megatruck, LHV: Operation: 120,000 km/year (102,000 km freighted and 18,000 km empty).
Activity: Working time: 1,906 h/year; in load 1,620; 8.5 h/day; activity ratio 225 days.
Technical: Engine power: 480 hp; MAM 60-ton; 7 axles; 14 tires; payload 40-ton.

Source: See Zofío et al. (2014: Table 1), Ortega et al. (2011) and Ortega et al. (2014). A specific assumption is that considering that the number of kms freighted and empty is identical for both HDV and LHV. This assumption is arguable since larger vehicles are more difficult to fill. Increasing the number of kms empty will slightly reduce the operating costs of LHVs.

Figure 1. Megatruck (LHV): model MST_{23} with 7 axles and MAM of 60-ton.



Source: Debauche and Decock (2007).

A description of the assumptions and parameters corresponding to each component of the operating cost costs for the megatruck can be found in Ortega et al. (2014). Table 3 summarizes the economic costs corresponding to the national average and compares it with the standard HDV in 2007. The total costs of the representative model amount to €144,239.3. Most of the total costs come from direct costs. Specifically, the direct costs for the megatruck are €135,155.6, more than 93.7% of the total cost. In contrast, indirect costs account for the remaining 6.3% (€9,144 per year). As anticipated, two components represent two-thirds of the total cost. They are fuel expenses and the cost of personnel, including accommodation and allowances, the cost of which are, €47,446.1 (32.9%) and €40,845.1 (28.3%), respectively. Next would be the cost of capital (amortization and financing), with a combined share of 13.7% (€19,789.3) – insurance (€7,363.3) and tires (€7,316.6), together represent 10% of total cost. The remaining percentage is divided between maintenance and repair expenses, and the payment of fees, taxes and tolls.

Upon examination of the difference with the standard HDV, the aggregate yearly cost of the megatruck is higher because of its larger size. In absolute terms, the LHV is €20,992.6 more expensive per year than the HDV (=€144,239.3−€123,246.7). But once these costs account for the payload of both configurations, the higher capacity of the megatruck shifts the balance in its favour, resulting in a 27.0% reduction in overall costs, to the tune of −0.01103 €/ton × km, as shown in the last column of Table 3. This difference is driven equally by the savings in fixed (time) and variable (distance) costs with reductions of −0.00538 €/ton × km and −0.00538 €/ton × km, respectively. Focusing on individual costs, about 50% of savings are attributable to labour-related expenses including salaries and accommodation and allowance: −0.00510 €/ton × km; these are followed by fuel,

Table 3. Difference in economic costs: Heavy Duty Vehicle (HDV) vs. Megatruck (MST_{23}), 2007. National Average. Unit: € at purchaser prices.

	Yearly cost (€)		Yearly cost (€/km)		Yearly cost (€/ton × km)		Yearly cost (€/ton × km) (freighted)∗		Difference
Cost components by vehicle	HDV	Megatruck MST_{23}	HDV	Megatruck MST_{23}	HDV	Megatruck MST_{23}	HDV (1)	Megatruck MST_{23} (2)	(2)-(1)
FIXED (time)	**51,083.8**	**55,912.7**	**0.42570**	**0.46594**	**0.01703**	**0.01165**	**0.02003**	**0.01370**	**−0.00538**
Capital	**16,308.5**	**19,789.3**	**0.13590**	**0.16491**	**0.00544**	**0.00412**	**0.00640**	**0.00485**	**−0.00131**
Amortization	13,584.7	16,557.2	0.11321	0.13798	0.00453	0.00345	0.00533	0.00406	−0.00108
Financing	2,723.8	3,233.2	0.02270	0.02694	0.00091	0.00067	0.00107	0.00079	−0.00023
Operating	**34,775.3**	**35,630.4**	**0.28979**	**0.29692**	**0.01159**	**0.00742**	**0.01364**	**0.00873**	**−0.00417**
Labour	27,375.1	27,375.1	0.22813	0.22813	0.00913	0.00570	0.01074	0.00671	−0.00342
Insurance	6,498.1	7,363.3	0.05415	0.06136	0.00217	0.00153	0.00255	0.00180	−0.00063
Taxes	902.1	970.3	0.00752	0.00809	0.00030	0.00020	0.00035	0.00024	−0.00010
VARIABLE (distance)	**63,318.9**	**78,882.0**	**0.52766**	**0.65735**	**0.02111**	**0.01643**	**0.02483**	**0.01933**	**−0.00467**
Fuel	36,754.1	47,446.1	0.30628	0.39538	0.01225	0.00988	0.01441	0.01163	−0.00237
Tires	6,096.6	7,316.6	0.05081	0.06097	0.00203	0.00152	0.00239	0.00179	−0.00051
Maintenance and repair	5,256.0	8,558.7	0.04380	0.07132	0.00175	0.00178	0.00206	0.00210	0.00003
Accomod. and allowances	13,470.0	13,470.0	0.11225	0.11225	0.00449	0.00281	0.00528	0.00330	−0.00168
Tolls	1,742.1	1,966.1	0.01452	0.01638	0.00058	0.00041	0.00068	0.00048	−0.00017
DIRECT	**114,402.7**	**135,155.6**	**0.95336**	**1.12630**	**0.03813**	**0.02816**	**0.04486**	**0.03313**	**−0.00998**
INDIRECT	**8,844.0**	**9,144.0**	**0.07370**	**0.07620**	**0.00295**	**0.00191**	**0.00347**	**0.00224**	**−0.00104**
TOTAL	**123,246.7**	**144,239.3**	**1.02706**	**1.20199**	**0.04108**	**0.03005**	**0.04833**	**0.03535**	**−0.01103**

Notes*:* Economic costs expressed at purchaser prices. ∗ Operation: 120,000 km/year (102,000 km freighted and 18,000 km empty).
Source: Own elaboration based on data from MFOM (2008b) and SPIM (2008).

which accounts for about 30% of the savings: −0.00237 €/ton × km. In this study, it is worth mentioning that we use different operating costs for each region of Spain, since many of these costs, such as, for example, fuel, salaries, taxes, etc., are region specific.[10]

3.2. From economic (purchaser) prices to national accounting (basic) prices, ESA95

All monetary values shown in the previous section correspond to purchaser prices, as reported in the operating balance of transportation firms. However, in order to translate these savings into reductions of the technical coefficients of the TIRIO, we first need to express them in basic prices according to the standard conventions in national accounts; i.e. exclusive of taxes payable on products and inclusive of subsidies receivable on products. A necessary step is to establish the relationship between the main economic macro-magnitudes of the TIRIO and the operational economic costs reflected in Table 3. Here we follow the ESA95 (Eurostat, 1996). Online Appendix A.2, Table A.2.1, shows the detailed correspondence between both accounting frameworks.

Hence, the challenge in this part of the study is to transform the operational costs of both the standard HDV and the megatruck from the purchaser prices shown in Table 3 into basic prices. The detailed procedure for each component of the national accounts is as follows:

Trade and transport margins. Starting with the supply table (base 2000) of 2007 (ST07), INE (2012), these margins are quantified for each of the sectors and correspond to intermediate consumptions. In this manner, savings in trade margins are allocated to sector 18 (CG: trade and repair of motor vehicles), and transport margins to the road freight transportation sector *S*25. Therefore, it is necessary to re-assign the margins to those sectors with which *S*25 is related, namely, where the innovation originates. In general and given the existing difficulties in obtaining information related to the margins of each region, the actual procedure consists in applying the adjustment weights obtained at the national level to all of the regions equally. This approximate solution is easy to apply and has a minimal or null effect on the results.

Taxes, less subsidies, on the products associated with intermediate consumptions. These values are also recovered from the ST07. Their weight is calculated over total supply at purchaser prices. Margins are calculated for the national set and applied *a posteriori* for all regions equally.

Special tax on hydrocarbons (STH). Consulting the data published by the State Tax Administration (STA) for 2007, it is possible to determine at a regional level, the amounts of this special tax, which are quite relevant for sector *S*25. Professional diesel refers to specific taxes on diesel type A. For vehicles that comply with the characteristics defined by law, for each litre, the STA reimburses to the owners a part of the fuel taxes. This fuel is subject to two types of special taxes: the STH and the tax on retail sales of specific hydrocarbons (TRSSH), popularly known as the ‘health tax’ or ‘health cent’. In this way, the STH, associated with the fuel consumed by both trucks, is calculated by accounting for the average discount applied when filling tanks at the gas stations, considering the annual reference distance travelled and the total annual fuel cost. The corresponding values in 2007 are considered for each region where these taxes are implemented.

[10] Individual tables for each region are available from the authors on request.

Table 4. Difference in economics costs between HDV and Megatruck. Unit: € at basic prices.

	National Average			
	Yearly cost (€/ton × km)		Difference	
Cost components by vehicle	HDV (1)	Megatruck – MST_{23} (2)	€/ton × km	% (2)/(1)
FIXED (time)	**0.01946**	**0.01326**	**−0.00619**	**68.17%**
Capital	**0.00637**	**0.00489**	**−0.00148**	**76.73%**
Amortization	0.00533	0.00411	−0.00122	77.08%
Financing	0.00105	0.00078	−0.00026	74.99%
Operating	**0.01308**	**0.00837**	**−0.00471**	**63.99%**
Labour	0.01074	0.00671	−0.00403	62.5%
Insurance	0.00235	0.00166	−0.00068	70.82%
Taxes	-	-	-	**67.23%∗**
VARIABLE (distance)	**0.01673**	**0.01257**	**−0.00416**	**75.12%**
Fuel	0.00772	0.00623	−0.00149	80.68%
Tires	0.00203	0.00152	−0.00051	75.01%
Maintenance and repairs	0.00102	0.00104	0.00002	101.77%
Accomod. and allowance	0.00528	0.00330	−0.00198	62.50%
Tolls	0.00068	0.00048	−0.0002	70.54%
DIRECT	**0.03619**	**0.02583**	**−0.01036**	**71.38%**
INDIRECT	**0.00346**	**0.00223**	**−0.00122**	**64.62%**
TOTAL	**0.03965**	**0.02807**	**−0.01158**	**70.79%**

Source: Own elaboration from data from MFOM (2008b) and SPIM (2008). See also Ortega et al. (2011) and Ortega et al. (2014).
∗The difference between tax figures at purchaser prices, with a null value at basic prices.

Taxes on insurance premiums. These taxes are also of special relevance for sector *S*25. They are obtained from the data relative to sector 84 (insurance services and pension plans) of the ST07. In fact, all net taxes on the products correspond to the taxes on insurance premiums. The taxable base corresponds to 6% of the total cost of the insurance premiums.

Table 4 shows the differences between the costs at basic prices of the current reference HDV and the megatruck (LHV). The data are used as the basis for calculating the variation in the technical coefficients of *S*25 for the TIRIO that are linked to the cost savings achieved by authorizing the operation of the megatruck. These savings are expressed, once again, in terms of euros per tonne and kilometre, €/ton × km. The adoption of the megatruck results in a reduction of almost 30% of the costs when measured in basic prices, with a reduction from 0.03965 to 0.02807 €/ton × km. Again, the main savings are attributable to labour (granted that the megatruck can be operated by a single driver) and fuel. Note that the overall savings are very similar to those reported in Table 3 at purchaser prices, although significant differences exist for the various components. The best example is fuel cost, given the high share of the special tax on hydrocarbons (STH) in the (purchaser) price as paid by firms at gas stations.

3.3. Market share of the 'megatruck'

In terms of intermediate consumption, the method followed to estimate the economy-wide savings associated with implementing the megatruck involves identifying the actual percentage of the ton × km that can be shifted to LHVs. The process implies that only a fraction of existing freight transportation can be transferred. This fraction or market share is the result of considering several restrictions related to vehicles' payload weight, type of good transported, logistical minimum range, and the adequacy of road infrastructure. To

Table 5. Potential market share of the megatruck. Unit: ton × kms freighted (thousand and %).

	Variable								
	Total ton × km (1)	HDV (> 26ton)		Cargo restrictions (0,1,3, 4)		Logistic range (> 250 km.)		High-capacity roads (highways)	
Regions	Thousand	Thousand	% (1)	Thousand	% (1)	Thousand	% (1)	Thousand	% (1)
Andalusia	30.810,6	20.338,0	66,0	16.251,1	52,8	9.005,1	29,2	7.204,0	23,4
Aragón	10.138,9	6.867,2	67,7	4.948,9	48,8	2.589,9	25,5	2.071,9	20,4
Asturias, P. de	4.989,1	3.299,1	66,1	2.559,0	51,3	1.307,7	26,2	1.046,2	21,0
Cantabria	3.029,5	2.065,0	68,2	1.701,1	56,15	842,3	27,8	673,8	22,2
Castilla y León	15.350,4	10.356,3	67,5	8.186,3	53,3	3.866,7	25,2	3.093,3	20,2
Castilla-La Mancha	13.380,7	9.017,7	67,4	7.298,9	54,6	3.590,3	26,8	2.872,3	21,5
Catalonia	28.854,2	19.490,9	67,6	15.093,0	52,3	8.800,1	30,5	7.040,1	24,4
Valencia	22.681,1	15.125,8	66,7	11.691,8	51,6	6.264,6	27,6	5.011,7	22,1
Extremadura	4.382,8	2.829,3	64,6	2.254,3	51,4	1.317,1	30,1	1.053,7	24,0
Galicia	12.696,8	8.566,6	67,5	6.505,4	51,2	3.817,3	30,1	3.053,9	24,0
Madrid	18.984,0	12.653,9	66,7	9.636,4	50,8	6.345,1	33,4	5.076,1	26,7
Murcia, R. de	6.908,9	4.580,9	66,3	3.545,1	51,3	1.874,6	27,1	1.499,7	21,7
Navarra, C.F. de	3.639,8	2.505,0	68,8	1.804,9	49,6	1.015,7	27,9	812,6	22,3
Basque Country	10.573,2	7.149,7	67,6	5.100,2	48,2	3.323,0	31,4	2.658,4	25,1
Rioja, La	1.778,1	1.202,5	67,6	959,0	53,9	544,4	30,6	435,5	24,5
Total	**188.198,2**	**126.047,8**	**67,1**	**97.535,5**	**51,8**	**54.503,8**	**28,6**	**43.603,1**	**22,9**

Source: Own elaboration based on MFOM (2008a), Ortega et al. (2011), Ortega et al. (2014), and Guzman et al. (2016).

determine the market shares under these restrictions we rely on the information provided by Spanish Road Freight Transportation Survey, MFOM (2008a). From this database, it is possible to obtain the value of ton × km transported with origin in each region, as well as additional variables such as its distribution by size of vehicle, distances to destinations, and type of cargo. Table 5 reports in the second column, identified by (1), the value for each region, which amounted 188.2 billion ton × km for the whole country in 2008.

First, following Ortega et al. (2011), none of the shipments performed with trucks below a 26-ton payload are candidates for the shift, because the economies of scale associated with the megatruck cannot be exploited. This implies that only shipments carried out with standard HDVs (rigid or articulated), which represented about 75% of the total in 2008, may be transferred to the megatruck. Of this amount, it is estimated that a credible transfer rate is around 50% for rigid vehicles and 90% for articulated vehicles. The third column in Table 5 shows the potential transferred amount of ton × km in each region under the previous restriction, which stands at 126.0 billion for the whole country. The following column reflects the percentages that these quantities represent in the observed amounts (1); amounting 67.1% of the country aggregate.

Secondly, not all types of goods can be taken into consideration as there are weight and volume restrictions depending on the type of cargo. Considering the regulations existing in 2008 for bulk shipments (e.g. liquid or solid), hazardous materials, products that pose increased risks, etc., the total percentage of goods limited by weight reasons was around 77% for rigid vehicles, and 69% for articulated vehicles. The results obtained after applying this restriction imply that the cumulated reduction with respect to the total observed amount of ton × km transported (1) is 48.2%, which means that the potential number of ton × km that could be transferred to the megatruck is further reduced to 97.5 billion, i.e. 51.8%.

Thirdly, from these remaining shipments, those corresponding to hauling distances below the minimum logistic range of 250 km are excluded. Again, Ortega et al. (2011) establish this threshold at which the megatruck becomes profitable (in comparison to the standard HDVs). These calculations are based on engineering cost functions ('freight curves') that relate optimal vehicle size and distance. The relationship is driven by the trade-off between distance-related costs expressed in €/ton × km, that are lower the larger is the vehicle because it can carry a larger payload cargo, and handling operations whose time costs per ton are higher (as they take longer) the larger is the vehicle. Table 5 shows that the cumulated reduction rises to 71.4%; the total being 54.5 billion ton × km, or 28.6% of the initial quantity.

Lastly, the actual figure for market potential is lower because it also depends on the existence of a suitable high-capacity road network. In this regard, Guzman et al. (2016; Fig. 2) map the specific roads that can accommodate megatruck traffic, without the need to resort to additional investments because these arcs have the required physical characteristics (minimum turning radio), and load-bearing capacity. The consideration of just these few corridors would be extremely restrictive when calculating the market share. For this reason, we adopt the proposal by Ortega et al. (2014, p. 157) of initially considering all shipments carried out through high-capacity roads ($\geq 2 \times 2$lanes highways). The reason is that existing highways in Spain would accommodate LHVs with slight infrastructure investments, whereas conventional roads would require substantial expending. To justify this investment, only those highways with an average daily heavy traffic greater than 1,500 vehicles are considered. Finally, the candidate highways must connect relevant logistical areas in the country. The consideration of these road restrictions results in an additional reduction in the number of ton × km by about 20%. This last filter brings the final number for the whole country to 46.3 billion ton × km, or 22.9% of the whole cargo being transported in Spain in 2007.

In general, these requirements can be summarized in the assumption that the megatruck is the preferred (minimum cost) choice when making shipments between freight hubs and logistic ports. From a regional perspective, it implies that all the islands (the Balearic Islands, the Canary Islands), the cities of Ceuta and Melilla, as well as the Extra-Regio conventions (residents living abroad (e.g. embassies) and other activities of public administrations that cannot be territorialized) are excluded from the analysis because they do not meet the necessary conditions to incorporate the megatruck.[11]

4. Weighting matrix: technical coefficients associated with innovation: TIRIO$^{\Omega}$

In this section, we proceed to determine the matrix of weighting factors $\mathbf{\Omega}$ associated with the megatruck that are later applied to the technical coefficients of *S*25 in the TIRIO, to calculate the impact of innovation on productivity. The weighting values are classified into three comprehensive groups: intermediate consumptions, compensation of employees and

[11] Legislation approving the use of LHVs was passed on 23 December 2017. Since then, adoption rates have followed a very slow pace because of the restrictions imposed on granting operating licenses, which are approved for specific origin-destination itineraries. Although the number of trips is increasing, the industry is in the early phases of the adoption curve, while no official statistics exist on the number of ton × km transported.

gross operating surplus/mixed income; taxes less subsidies on products and production; and trade and transport margins.

4.1. Weighting of intermediate consumption, compensation of employees and gross operating surplus

This group constitutes the weighting matrix $\mathbf{\Omega}1$. The process can be summarized by the following steps:

First, we establish the market share of each region r, in terms of ton $\times$ km transferred to the megatruck, $c^{r}{}_{25}$ (Table 6).

Second, we identify the economic magnitudes of the TIRIO, the fixed (time) or variable (distance) cost structure, which are modified by introducing those of the megatruck. Here, we use the correspondence established in Appendix A.2, Table A.2.1. Subsequently, we calculate the new technical coefficients. Intermediate inputs require additional treatment in those sectors in which there is partial identification between operational costs and the activity sector. This situation arises, for example, with tires, which are included in sector $S9$ (DH, rubber and plastic transformation industry). In these cases, the results associated with intermediate consumption are obtained from the use table (UT07) of the national accounts (with base 2000), which are used to calculate the share of such a product in its corresponding product category. UT07 is divided into 118 products, allowing for the estimation of the degree of participation of each product in $S25$, based on category 47 (land and pipeline transport) in which $S25$ is included. In this way, we use $s^{m;47}_{j,s;25}$ to denote the weight in the intermediate consumption of product j in UT07, with which s is identified. For example, to calculate the contribution of tires to the rubber and plastic industry (S9, DH), the weight of rubber products is considered, ($j=36$, $_{j\in m}$) in the subset m ($m=36$, 37), which includes the plastic materials ($j=37$): $s^{34,37;47}_{36,9;25} = 0.944$.

Third, based on the percentage of the difference in costs at basic prices between both vehicles, denoted as $m^{r}_{s,25}$ and presented in Table 4, we define the reduction in intermediate consumptions occurring in sector s, used by $S25$ of region r as $1 - m^{r}_{s,25}$. The reduction coefficient varies for each region r, but it is the same for the entire production with origin in r and m with any destination k.

Finally, the weighting values for the different sectors shown Appendix A.2 are obtained in the following way:

(1) For the intermediate consumption of sector s that is used by $S25$ of r is based on the preceding coefficients. The weighting is $\omega 1^{r}_{s,25} = 1 - s^{m;47}_{j,s;25} c^{r}_{25}(1 - m^{r}_{s,25})$.
(2) For the payment of employees of $S25$ in r, it becomes $\omega 1^{r}_{25,l} = 1 - c^{r}_{25}(1 - m^{r}_{25,l})$.
(3) For the reduction in amortization, which requires an estimate of its weight on GOS/IM. So, we calculate the weight of fixed capital consumption over this in institutional sectors: households and non-financial societies in the National Accounts (base 2000), this yielding 32.47%. The weight applicable to the gross operating surplus/mixed income of S25 in r is$\omega 1^{r}_{25,c} = 1 - 0.3247 c^{r}_{25}(1 - m^{r}_{25,c})$.

Table 6. Weighting matrices $\boldsymbol{\Omega}$: $\boldsymbol{\Omega}1$, $\boldsymbol{\Omega}2$ and $\boldsymbol{\Omega}3$ of $S25$ for calculating the new technical coefficients in TIRIO$^{\boldsymbol{\Omega}}$.

Macro-magnitude TIRIO$^{\Omega}$/Concepts	Regions	Andalusia	Aragón	Asturias, P. de	Cantabria	Castilla y León	Castilla-La Mancha	Catalonia	Valencia	Extremadura	Galicia	Madrid	Murcia, R. de	Navarra, C.F. de	Basque Country	Rioja, La
Sectors	**Products**								$\omega 1^r_{s,25}$							
$S9$ (DH). The rubber and plastic transformation industry	Tires	0.945	0.952	0.951	0.948	0.952	0.949	0.942	0.948	0.943	0.943	0.937	0.949	0.947	0.941	0.942
$S14$ (DM). Fabrication of transportation material	Maintenance (parts)	1.001	1.001	1.001	1.001	1.001	1.001	1.002	1.001	1.002	1.002	1.002	1.001	1.001	1.002	1.002
$S16$ (DF + EE). Energy industry. Distribution of energy. gas and water	Fuel	0.960	0.965	0.964	0.962	0.966	0.964	0.959	0.962	0.959	0.959	0.955	0.963	0.962	0.957	0.958
$S18$ (GG). Trade and repair of motor vehicles	Repairs	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001
$S28$. Supporting and auxiliary transport activities	Tolls	0.987	0.985	0.990	0.998	0.995	0.995	0.997	0.992	0.894	0.976	0.964	0.995	0.993	0.997	0.985
$S30$. Financial intermediation	Finan. and insur.	0.969	0.973	0.972	0.970	0.973	0.971	0.967	0.970	0.968	0.968	0.964	0.971	0.970	0.966	0.967
Macro-magnitude	**Components**								$\omega 1^r_{25,g}$							
$g =$ l. Compensation of employees	Labour, accom. and allowance	0.912	0.923	0.921	0.917	0.924	0.920	0.909	0.917	0.910	0.910	0.900	0.919	0.916	0.906	0.908
$g =$ c. Gross operating surplus/mixed income	Amortization	0.982	0.985	0.984	0.983	0.985	0.984	0.982	0.983	0.982	0.982	0.980	0.984	0.983	0.981	0.982
Macro-magnitude	**Components**								$\omega 2^r_{25,i}$							
$i = tpos$. Taxes less subsidies on products	$z^{rr}_{sj}, z^{kr}_{sj}, z^{mr}_{sj}$	0.975	0.979	0.988	0.994	0.988	0.985	0.983	0.987	0.968	0.978	0.98	0.984	0.988	0.995	0.977
$i = g = t$. Other taxes less subsidies on production	Taxes	0.910	0.940	0.942	0.958	0.942	0.947	0.941	0.880	0.920	0.910	0.929	0.921	0.946	0.950	0.924
Sectors	**Margins**								$\omega 3^r_{S,25}$							
$S18$ (GG). Trade and repair of motor vehicles	Trade	0.981	0.983	0.988	0.973	0.930	0.974	0.978	0.992	0.975	0.981	0.987	0.953	0.992	0.996	0.977
$S25$. Road freight transportation sector	Transport	0.991	0.993	0.997	1.001	0.995	0.999	0.998	0.995	0.969	0.996	0.991	0.996	0.999	1.001	0.997

Source: Own elaboration, based on Zofío et al. (2014). See also Table A.2.1.

4.2. Weighting of taxes less subsidies on products (tpos) and other taxes less subsidies on production (v_t)

For *tpos* we chose to decrease proportionally total intermediate consumption reduction (at basic prices) of *S*25 in *r*:

$$\omega 2^r_{tpos,25} = \left(\sum_k \sum_s \omega 1^r_{s,25} z^{kr}_{s,25} + \sum_s \omega 1^r_{s,25} z^{mr}_{s,25}\right) / \left(\sum_k \sum_s z^{kr}_{s,25} + \sum_s z^{mr}_{s,25}\right)$$

For v_t, this belongs to the national *Tax on Mechanically Powered Vehicles* (*TMPV*). It is distributed among regions according to the numbers of heavy vehicles, $\#\text{HDV}s^r_{25}$. A reduction in tax costs is applied to this value per ton × km of real freight, based on market share, and it is transferred to $v_{25,t}$. The expression for the weight multiplier is as follows: $\omega 2^r_{t,25} = 1 - \text{TMPV} \times \#\text{HDVs}^r_{25} \times c^r_{25} \times (1 - m^r_{t,25})/v^r_{t,25}$.

4.3. Weighting of trade and transport margins

The weighting of trade and transport margins ($\omega 3^r_{s,25}$) is circumscribed by the intermediate consumption of tires, parts and fuel which, according to Table A.2.1, are identified with sector *S*9; fabrication of transportation material (DM, S14) and the energy industry, the distribution of energy, gas and water (DF + EE, S16) of the TIRIO. The procedure for the specific components is as follows:

Trade margins: the weight of these is calculated in sector *s* of the TIRIO, based on their percentage of the offer of product *j* in the supply table 2007 ($cm_{j,s}$). This value is the weight of the intermediate consumption from the TIRIO occurring in the trade and repair of motor vehicles (*S*18), which varies due to $\omega 1^r_{s,25}$. The formula is as follows:

$$\omega 3^r_{18,25} = 1 - \begin{pmatrix} cm_{36,9}(1 - \omega 1^r_{9,25}) \left(\sum_{k=1}^R z^{kr}_{9,25}\right) + cm_{53,14}(1 - \omega 1^r_{14,25}) \times \\ \left(\sum_{k=1}^R z^{kr}_{14,25}\right) + cm_{12,16}(1 - \omega 1^r_{16,25}) \left(\sum_{k=1}^R z^{kr}_{16,25}\right) \end{pmatrix} / \left(\sum_{k=1}^R z^{kr}_{18,25}\right)$$

Transport margins: these are calculated in the same way, but referring to *S*25 and to the transport margins in the supply table 2007 ($tm_{j,s}$):

$$\omega 3^r_{25,25} = 1 - \begin{pmatrix} tm_{36,9}(1 - \omega^r_{9,25}) \left(\sum_{k=1}^R z^{kr}_{9,25}\right) + tm_{53,14}(1 - \omega 1^r_{14,25}) \times \\ \left(\sum_{k=1}^R z^{kr}_{14,25}\right) + \text{tm}_{12,16}(1 - \omega 1^r_{16,25}) \left(\sum_{k=1}^R z^{kr}_{16,25}\right) \end{pmatrix} / \left(\sum_{k=1}^R z^{kr}_{25,25}\right)$$

Table 6 shows the results of the values of the three weighting matrices: $\mathbf{\Omega}1$, intermediate consumptions; $\mathbf{\Omega}2$, taxes less subsidies on products and other taxes less subsidies on production; and $\mathbf{\Omega}3$, trade margins and transport margins for those sectors that trade with *S*25. Multiplying the existing matrix of technical coefficients by the above matrix of weights, we obtain the new matrix capturing the technical innovation, which is embedded in $\text{TIRIO}^{\mathbf{\Omega}}$.

5. Results: transportation sector, innovation, productivity and economy-wide benefits

First, we highlight the overall importance of the transportation sector in the Spanish economy. This allows calculating the different backward and forward linkages existing in the multiregional-multisectoral IO economy characterized by the TIRIO. This multiplicity of effects induces a sequence of trade flows that we have structured as presented in Table 1, thereby rendering the methods amenable to empirical analysis despite their complexity. Subsequently, in Sections 5.2 and 5.3 below, we resort to the matrix algebra presented in Section 2.3 to calculate the effects of innovation, once the current matrix of technical coefficients, $\mathbf{A}^d$ in (3), has been replaced with the new one associated with the introduction of the megatruck, using the weights reported in Table 6; i.e. relying on TIRIO$^{\mathbf{\Omega}}$.

5.1. Importance of interregional spillover effects from transportation: GVA

While the analysis of an increase in demand in the transportation sector can be measured taking into consideration a whole array of variables (e.g. primary inputs, intermediate consumption, etc.), we focus here on the main one, which represents the main aggregate production level for the regions. Figure 2 presents bilateral spillovers in terms of GVA between selected regions (Equation A7 in Appendix A). As usual, these values correspond to a simulation associated with a unit increase in the final demand of a region r (equivalent to thousand euros since this is the unit of measurement in the TIRIO), inducing an increase in the (interregional) spillovers (trade flows) on region k. These flows are identified as (4) in the third column of Table 1. The five regions that record the greatest value-added in the TIRIO transportation sector ($S25$) considering unit increments in all cases are shown in alphabetical order. Following the first pair of regions, Andalusia ↔ Catalonia, the model indicates that a thousand euros increment in the aggregate final demand $\Delta\mathbf{F}^r$ in Catalonia (region r on region k), results in an increment in GVA in Andalusia of €167 (i.e. 0.167 thousand €), while if the increase is in Andalusia, then GVA in Catalonia increases by €882 (k on r). Therefore, the trade balance for Andalusia is negative. In this figure, we can observe that Catalonia and Madrid are the main beneficiaries when the final demand in the remaining regions increases (and the opposite is so in case of an economic recession), as the spillover effects are greater in value than the initial change in the region of origin. For example, the growth in Madrid's GVA by €2,103 more than doubles the €1,000 initial increase in final demand when it takes place in the Basque Country. Also, Tables A.1.1 and A.1.2 in Appendix A present the underlying domestic effects (in the main diagonal) and spillover effects, identified as 'net effects' in Table 1, from the backward and forward perspectives. The total (national) net effect on the economy is respectively shown in either the last row or the last column of the corresponding table.[12]

The aggregate spillover effects (backward and forward) between regions are presented in Table 7 for different sets of sectors. The first block of three columns shows the effects on all sectors of the economy less the whole transportation sector (including all four modes: road, train, sea and air, as well as means: freight and passengers); i.e. all sectors, S, less the

[12] The aggregate bilateral spillover effect reported in Figure 2 can be recovered from Table A.1.1 by adding the effects corresponding to the road freight transport sector, $S25$, those of the whole transport sector ST less $S25$, and finally, the economy as a whole S less ST, i.e. $S = (S{-}ST){+}(ST{-}S25){-}S25$.

Figure 2. Bidirectional spillover trade flows. Gross Value Added. ΔF_j^r, Unit: thousand €.

Source: Own elaboration.

transportation sector, ST, denoted by $S-ST$. For example, Andalusia generates €3,364 in GVA in the remainder of the sixteen regions (i.e. more than three times the initial shock simulated), compared to the forward effect of the rest of the regions back to Andalusia, which is almost six-fold reaching €5,818. So, considering the aggregate value of both effects for Andalusia, €9,182, 36.6% of the total corresponds to backward effects, while 63.4% represents forward effects; i.e. the effect of the increment in the final demand of all of the sectors (except the transportation sector) in the national economy generates a greater GVA in Andalusia than that resulting from the increment in the final demand of Andalusia itself.

The second block of three columns refers to the transportation sector (ST) less the sector corresponding to road freight transportation, $S25$ ($ST-S25$). For Andalusia, a value-added of €826 is generated in the remaining regions of the national economy (drag effect) while, given the subsequent final demand increases (drive effect), the value-added generated in the aggregate of sector ST-$S25$ of Andalusia is €434. Note, however, that Catalonia and Madrid are the only regions in which the forward effect is greater than the backward effect. In 2008 Catalonia and Madrid respectively represented 14.7% and 14.1% of the Spanish GDP (INE, 2020), and given their economic size they generate larger spillovers in other regions than those received from them. For Catalonia, of the total effect of about €1,754, the backward effect represents 28.4% (€498), and the forward effect the remaining 71.6% (€1,256), due also to the elevated presence of other modes and means of transport in this region.

Finally, the third block of three columns shows the results corresponding to the freight road transportation sector $S25$: the regions that record the highest forward share are Andalusia, with 73.8% (€320), Catalonia with 89.5% (€705), Valencia with 84.0% (€335) and Madrid with 84.3% (€660). The fourth block shows the effect on the entire sectors of the economy, S, where both effects cancel each other out at the national level. Note that the aggregated backward and forward effects for all sectors (S) corresponding to a regional economy, are the summation of the previous effects for each subset of sectors: $S=(S-ST)+(ST-S25)+S25$.

We conclude that the transportation sector generally plays a relevant role in the Spanish economy's interregional trade flows, with average values approximating 25% of the total backward and forward effects corresponding to the whole economy (all sectors S). For example, in Madrid, the transportation sector accounts for 49.3% ($=(1{,}504+122)/3{,}296$) of the overall backward effect for the rest of the regions, while the subsequent increase

Table 7. Spillover effects: backward vs. forward. Gross Value Added. Unit: thousand €.

Sectors / Regions	Rest of sectors: *S-ST*			Rest of transportation sectors: *ST-S25*			Road freight transport. sector: *S25*			All sectors: *S*		
	Backward	Forward	Balance	Backward	Forward	Balance	Backward	Forward	Balance	Backward	Forward	Balance
Andalusia	3.364	5.818	−2.454	0.826	0.434	0.392	0.114	0.320	−0.206	4.303	6.371	−2.268
Aragón	5.020	2.851	2.169	1.188	0.072	1.116	0.158	0.084	0.074	6.367	3.007	3.359
Asturias, P. de	4.183	1.747	2.436	1.250	0.093	1.157	0.159	0.044	0.115	5.392	1.884	3.708
Balearic Islands	3.337	1.733	1.604	0.805	0.163	0.642	0.154	0.018	0.136	4.296	1.914	2.382
Canary Islands	1.438	1.292	0.146	0.453	0.224	0.229	0.024	0.017	0.007	1.916	1.333	0.383
Cantabria	4.358	0.808	3.750	0.885	0.032	0.853	0.260	0.033	0.227	5.703	0.873	4.830
Castilla y León	4.704	3.976	0.728	1.041	0.078	0.963	0.111	0.064	0.047	5.856	4.118	1.738
Castilla-La Mancha	4.875	2.547	2.329	1.988	0.099	1.889	0.229	0.166	0.064	7.093	2.811	4.282
Catalonia	1.672	17.858	−16.185	0.498	1.256	−0.758	0.083	0.705	−0.622	2.253	19.819	−17.566
Valencia	3.534	7.879	−4.345	1.116	0.662	0.454	0.064	0.335	−0.271	4.714	8.876	−4.162
Extremadura	6.238	0.680	5.559	0.989	0.020	0.969	0.166	0.018	0.148	7.393	0.717	6.676
Galicia	4.636	2.744	1.892	1.359	0.050	1.309	0.257	0.100	0.157	6.251	2.894	3.357
Madrid	3.296	27.403	−24.107	1.504	2.626	−1.122	0.122	0.660	−0.537	4.922	30.688	−25.766
Murcia, R. de	4.324	1.590	2.734	1.385	0.060	1.325	0.101	0.094	0.007	5.810	1.745	4.066
Navarra, C.F. de	4.399	1.450	2.949	0.586	0.061	0.525	0.182	0.086	0.096	5.167	1.597	3.569
Basque Country	3.848	5.973	−2.125	0.990	0.256	0.734	0.212	0.210	0.002	5.050	6.439	−1.388
Rioja, La	5.978	0.949	5.028	1.085	0.014	1.071	0.238	0.024	0.214	7.301	0.987	6.314
Ceuta y Melilla	5.634	0.055	5.578	0.674	0.013	0.661	0.111	0.001	0.110	6.419	0.069	6.349
Extra-Regio	0.145	0.008	0.137							0.145	0.008	0.137
National	**75.183**	**87.361**	**−12.177**	**18.622**	**6.213**	**12.409**	**2.746**	**2.978**	**−0.232**	**96.552**	**96.552**	**0.000**

Source: Own elaboration.

Table 8a. Productivity and effects on macro-magnitudes in *S*25 (fixed final demand). TIRIO$^{\Omega}$. Unit: thousand € and %.

Regions \ Macro-Magnitude TIRIO$^{\Omega}$	Intermediate demand at acquisition prices	Comp. of employees	Other taxes less subsidies on production	Gross operating surplus/mixed income	Gross value added	Production at basic prices	Gains on productivity
	$\underline{z}_{25}^{r}$ (16)	$\underline{v}_{25,l}^{r}$ (16)	$\underline{v}_{25,t}^{r}$ (16)	$\underline{v}_{25,c}^{r}$ (19)	$\underline{v}_{25}^{r}$ (16)	$\underline{x}_{25}^{r}$ (7)	δ_{j}^{r} (18)
	1	2	3	4	5 = 2+3+4	6 = 1+5	7
Andalusia	2.810.063	902.381	6.437	1.566.835,21	2.475.653	5.285.716	3,462%
Aragón	659.387	310.261	1.654	392.693	704.608	1.363.995	3,347%
Asturias, P. de	328.678	131.490	931	200.703	333.124	661.802	2,758%
Balearic Islands	316.160	108.852	233	87.617	196.701	512.861	
Canary Islands	401.800	152.812	695	201.421	354.929	756.729	
Cantabria	629.844	130.664	863	192.134	323.661	953.505	1,930%
Castilla y León	1.190.768	412.809	2.725	705.105	1.120.638	2.311.406	2,527%
Castilla-La Mancha	1.734.914	432.528	3.279	720.487	1.156.294	2.891.208	2,614%
Catalonia	4.183.232	1.326.015	9.708	2.046.945	3.382.667	7.565.900	3,169%
Valencia	1.480.013	621.748	2.680	974.832	1.599.260	3.079.273	2,966%
Extremadura	238.580	107.459	1.111	174.084	282.654	521.234	4,126%
Galicia	911.461	337.689	1.788	483.393	822.870	1.734.331	3,587%
Madrid	2.421.772	598.567	7.014	1.042.664	1.648.245	4.070.016	3,326%
Murcia, R. de	663.187	330.757	1.256	462.289	794.302	1.457.489	3,211%
Navarra, C.F. de	629.552	161.381	956	277.179	439.515	1.069.067	2,503%
Basque Country	1.417.031	390.414	2.819	624.395	1.017.627	2.434.658	2,422%
Rioja, La	156.138	41.742	373	76.717	118.832	274.969	3,332%
Ceuta y Melilla	52.730	17.518	−69	23.560	41.010	93.740	
Extra-Regio							
Total	**20.225.308**	**6.515.086**	**44.453**	**10.253.052**	**16.812.591**	**37.037.899**	**2,9461%**

(*continued*).

Table 8b. Continued.

Regions \ Macro-Magnitude TIRIO$^{\Omega}$	Intermediate demand at acquisition prices $\underline{z}^r_{25}$ (16)	Comp. of employees $\underline{v}^r_{25,l}$ (16)	Other taxes less subsidies on production $\underline{v}^r_{25,t}$ (16)	Gross operating surplus/mixed income $\underline{v}^r_{25,c}$ (19)	Gross value added $\underline{v}^r_{25}$ (16)	Production at basic prices $\underline{x}^r_{25}$ (7)	Gains on productivity δ^r_j (18)
	1	2	3	4	5 = 2+3+4	6 = 1+5	7
Andalusia	−2,484%	−8,790%	−9,040%	11,207%	2,922%	−0,024%	
Aragón	−2,143%	−7,670%	−6,013%	11,409%	2,076%	−0,008%	
Asturias, P. de	−1,227%	−7,872%	−5,845%	8,261%	1,222%	−0,009%	
Balearic Islands							
Canary Islands							
Cantabria	−0,568%	−8,351%	−4,247%	8,732%	1,089%	−0,012%	
Castilla y León	−1,223%	−7,372%	−5,840%	7,363%	1,299%	−0,016%	
Castilla-La Mancha	−1,551%	−8,070%	−5,353%	9,893%	2,364%	−0,022%	
Catalonia	−1,711%	−9,170%	−5,917%	11,166%	2,148%	−0,022%	
Valencia	−1,340%	−8,301%	−12,053%	8,487%	1,242%	−0,016%	
Extremadura	−3,249%	−9,038%	−8,030%	12,005%	2,870%	−0,024%	
Galicia	−2,246%	−9,033%	−9,040%	12,679%	2,378%	−0,015%	
Madrid	−2,055%	−10,074%	−7,182%	12,553%	1,044%	−0,052%	
Murcia, R. de	−1,571%	−8,152%	−7,961%	9,436%	1326,000%	−0,013%	
Navarra, C.F. de	−1,230%	−8,394%	−5,467%	8,801%	1,755%	−0,024%	
Basque Country	−0,520%	−9,437%	−4,967%	8,329%	0,710%	−0,010%	
Rioja, La	−2,286%	−9,190%	−7,617%	11,464%	3,156%	−0,007%	
Ceuta y Melilla							
Extra-Regio							
Total	**−1,644%**	**−8,409%**	**−6,976%**	**9,992%**	**2,002%**	**−0,022%**	

Source: Own elaboration.

in GVA that goes to the transportation sector in return (forward effect) is rather low at 12% (=(2,626 + 660)/27,403). Similar or even higher shares can be found in other large Autonomous Communities such as Catalonia, whilst the values reduce for smaller regions. Whether the original backward effect results in higher or lower forward effects, is also relevant when determining the importance of the transportation sector regionally or nationally, in the event of an external shock such as that produced by the innovation associated with the megatruck. This is studied in the next section.

5.2. *Demand model and innovation*

The innovation characterized by the adoption of the megatruck, Model MST_{23} (Figure 1 and Table 4), given potential market shares in each region (Table 5) results in productivity gains by way of cost reductions throughout the entire $TIRIO^{\Omega}$ (Table 6). For the demand model presented in Section 2.1, the final demand is kept constant, and the gains in productivity are expressed in the gross operating surplus/mixed income (19). In addition, for the price model (Section 2.2), we observe additional increments in the GOS/MI resulting from the assumption of price rigidities for the innovative transportation sector *S*25 (i.e. considered as a flex-price sector) compared to changing prices in the remaining sectors (i.e. fix-price sectors).

Tables 8(a) (upper part in absolute values) and 8(b) (lower part reporting the percentage change in the initial values) present the results of the innovation within the road transportation sector *S*25 in terms of costs reductions, profit and value-added increase, and the resulting productivity coefficient, Equation 16, $\delta^{r}_{25} = 0.0295$ (2.9461%). Once this coefficient is elevated to $\underline{\underline{v}}_{c,25}$, expression (20), gross operating surplus/mixed income, GOS/MI, amounts to €10,253.0 million; i.e. a 9.99% increase in the initial value at €9,321.6 million – see also Table 9 presents the results for the whole Spanish economy. The resulting GOS/MI by regions shows that in absolute terms, Catalonia, Andalusia, Madrid and Valencia represent 54.9% in $\underline{\underline{v}}^{r}_{c,25}$. In terms of productivity, the greatest gains come from Extremadura (4.13%), Galicia (3.59%) and Andalusia (3.46%). Figure 3 maps the productivity gains across the Spanish regions. Interestingly, those exhibiting the highest values and ranking in the top quartile are peripheral, with the regions concentrating most of the country's economic activity, e.g. Madrid, Catalonia, ranking at the next level. As for gross value added, the greatest increase takes place in La Rioja (3.16%), Madrid (3.04%), Andalusia (2.92%) and Extremadura (2.87%). A lower relative impact occurs in the Basque Country (0.71%) and Cantabria (1.09%) – see Table 8a(b). With regard to the gross operating surplus, the greatest increments are recorded in Galicia (12.68%) and Madrid (12.55%), which are approximately 2.6 percentage points greater than the figure of 9.99% representing the overall national impact. In La Rioja, Aragon, Andalusia and Catalonia, the growth is in the range of 11%-12%. In terms of compensation of employees, Madrid records the greatest savings (10.06%).

Regarding the innovation for the economy as a whole, Table 9 shows the main aggregates for *S*25, along with those of the remaining transportation sectors (*ST*-*S*25), the rest of the sectors (*S*-*ST*) and the economy as a whole (*S*). All these aggregates are also compared with the initial situation ($TIRIO^{\Omega}/TIRIO-1$). As can be seen, the gross operating surplus/mixed income for the whole economy increases by 0.19% over the entire system, mainly driven

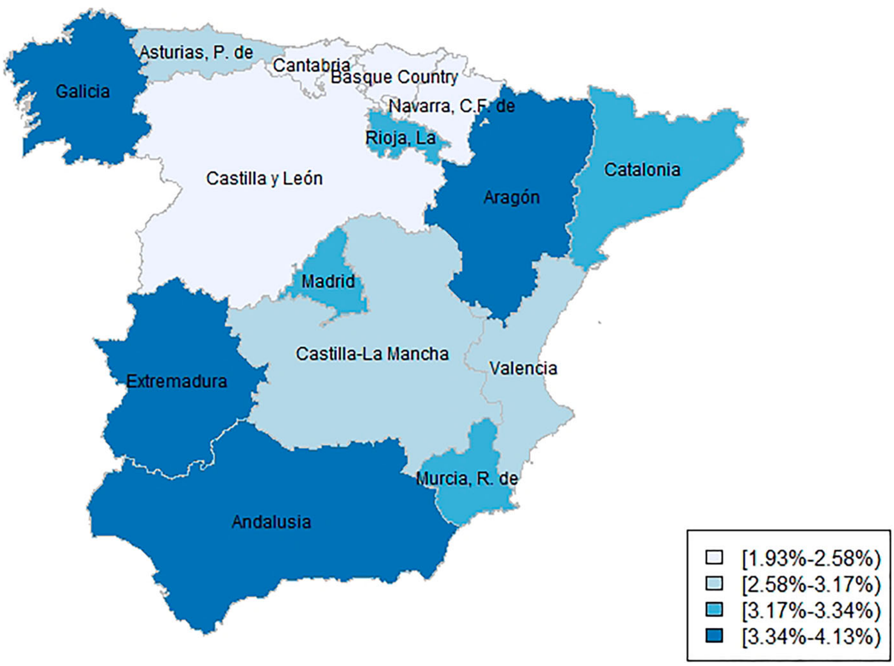
Table 9. Impact of the innovation on macro-magnitudes. Unit: thousand €.

Sectors / Macro-magnitude	Initial situation				(+/-) Variation as regards the initial situation (thousand €)			
	Road freight transportation sector: *S25*	Rest of transportation sectors: *ST-S25*	Rest of sectors: *S-ST*	All sectors: *S*	Road freight transportation sector: *S25*	Rest of transportation sectors: *ST-S25*	Rest of sectors: *S-ST*	All sectors: *S*
Gross operating surplus/mixed income	9,321,607	15,135,862	417,460,532	441,918,000	931,445	−7,554	−76,303	847,588
Compensation of employees	7,113,234	11,593,518	483,475,248	502,182,000	−598,147	−5,633	−44,504	−648,283
Other taxes less subsidies on production	47,786	83,994	592,220	724,000	−3,333	−43	−1,438	−4,814
Gross value added	16,482,626	26,813,374	901,528,000	944,824,000	329,964	−13,229	−122,244	194,491
Intermediate demand at acquisition prices	20,563,291	35,774,127	1,070,306,581	1,126,644,000	−337,983	−17,228	−194,926	−550,137
Production at basic prices	37,045,917	62,587,501	1,971,834,581	2,071,468,000	−8,019	−30,457	−317,170	−355,646

Sectors / Macro-magnitude	Final situation				(+/-) Variation as regards the initial situation (%)			
	Road freight transportation sector: *S25*	Rest of trans-portation sectors: *ST-S25*	Rest of sectors: *S-ST*	All sectors: *S*	Road freight transportation sector: *S25*	Rest of trans-portation sectors: *ST-S25*	Rest of sectors: *S-ST*	All sectors: *S*
Gross operating surplus/mixed income	10,253,052	15,128,308	417,384,229	442,765,588	9.992%	−0.050%	−0.018%	0.192%
Compensation of employees	6,515,086	11,587,886	483,430,745	501,533,717	−8.409%	−0.049%	−0.009%	−0.129%
Other taxes less subsidies on production	44,453	83,951	590,782	719,186	−6.976%	−0.051%	−0.243%	−0.665%
Gross value added	16,812,591	26,800,144	901,405,756	945,018,491	2.002%	−0.049%	−0.014%	0.021%
Intermediate demand at acquisition prices	20,225,308	35,756,900	1,070,111,655	1,126,093,863	−1.644%	−0.048%	−0.018%	−0.049%
Production at basic prices	37,037,899	62,557,044	1,971,517,411	2,071,112,354	−0.022%	−0.049%	−0.016%	−0.017%

Source: Own elaboration.

Figure 3. Productivity gains in Spanish regions.



by the road transportation sector that increases by 10% as mentioned previously. Interestingly, the increase in profits of the road freight transportation sector takes place at a minor expense of the remaining transportation sectors, which see their profits marginally reduced by −0.05%. Correspondingly, this does not translate into any obvious gain for the remaining sectors of the economy which see a marginal reduction of −0.02% in the gross operating surplus. These macroeconomic results suggest that the road freight transportation sector gains very limited market share at the expense of other modes; mainly train and air. Furthermore, given its current share of about 85% in overall freight transportation, there is not much room for these substitution effects. Similar magnitudes are observed for the gross value added of the rest of the transportation sectors and the remainder of the economy. In particular, the innovation for the whole economy (S) increases the overall value added by €194.5 million (a 0.02% increase with respect to the initial situation), mainly driven by the increase in $S25$ which amounts to €330.0 million (2.00%).

These results show that, from the demand model perspective, the benefits of the megatruck mainly remain confined within the innovative sector; therefore, road transport firms appropriate the innovation in the form of higher margins and, thus, do not pass the benefits forward to improve profits and value-added across the rest of the economy. Since the use of LHVs was approved in Spain in December 2017, applications for new licenses have been mainly driven by large companies specialized in long-distance hauling and providing supply chain logistics for large groups (automakers, wholesale and retail, parcel distribution, etc.). The reason is that larger companies are better positioned to reap the benefits of the scale and distance economies offered by LHVs. Despite the relative low concentration of the road transportation sector as a whole, the adoption of LHVs in Spain will certainly result in larger companies in this growing market niche, following observed trends in other major EU countries. Nevertheless, the consolidation of the LHVs in Spain has been hampered due to numerous administrative limitations on new licenses. The adoption of the megatruck has faced intense opposition from trade unions and left-wing legislators, because its short-term biased technological change against labour threatens small – one driver/one truck – firms. This explains why LHVs are not taking off and their growth is still at the early stages of adoption. To the extent that the megatruck results in less effective competition due to increasing market concentration, the benefits associated with its cost reductions will not be passed downstream to consumers. The concentration in the market is further aggravated by recent waves of mergers and acquisitions, which have substantially increased the market power of firms.[13]

The flex/fix price models introduced by Carter (1990) – Section 2.3.3, enables us to simulate the economy-wide consequences of either the above scenario associated with increasing market power, by which the transportation sector is considered as flex-price, or an opposite situation where effective competition would predominate and the benefits would be passed to consumers through lower prices, i.e. considering the transportation sector as fix-price.

5.3. Flexible/fix price model and innovation

Under the assumptions of the price model presented in Section 2.3.3, Table 10 shows the economic impact on prices and gross operating surplus/mixed income when simultaneously applying the innovation to *S*25 in all regions. Specifically, given the increasing concentration of the LHVs transportation sector previously justified, this simulation exercise assumes that the price structure of *S*25 in each region is *Flexible*, while in the remainder of the different regions and sectors of *S*25, and in the innovative region, it is *Fixed*.

In Table 10, the technical coefficient of GOS/MI is denoted by $\bar{v}^r_{25,c}$, Equation (2) – after the innovation $\underline{v}^r_{25,c}$ (20) – while the coefficients $\underline{v}^{r\,\mathrm{flex}}_{25,c}$ (26) are obtained by applying the model of flexible/fixed prices. In order to measure the impact of an absolute value, we use the initial production of *S*25 in the TIRIO, Equation (1), instead of keeping the final demand constant and deriving the new production levels according to (17). The results reported in columns [2] and [3] show that the sectors with rigid prices, when compared to the remainder of the sectors with variable prices, experience an increase in gross operating surplus/mixed income that is greater than their productivity gain without any assumptions being made about price structures (i.e. the standard result from the previous demand model); for example, the additional gain in productivity of circa 0.163% for Andalusia, reported in column [11].

As previously indicated, in terms of gross value added, the five regions with the greatest weight in terms of value-added in the transportation sector do not necessarily experience the greatest extra gains in productivity, either in absolute or relative terms (last columns of Table 10). The greatest gains are observed for Castilla-La Mancha (6,241 thousand €, equivalent to a 0.87% increase over the initial value), Catalonia (4,859 and 0.24%), the Basque Country (2,915 and 0.47%) and Andalusia (2,553 and 0.163%). In the cases of the

[13] For 2015 only, we refer the reader to the following list of mergers and acquisitions (see https://bit.ly/2kM5iUb). Some of the current trends in M&A are worldwide but have country effects.

Table 10. Flexible/rigid price model. Units: thousand € and %.

Macro-magnitude / Regions	Production at basic prices	Gross operating surplus/mixed income (technical coefficients)			% over initial situation [2]		Gross operating surplus/mixed income (thousand €)			Extra-gain on productivity	
	x^r_{25} (1)	$\bar{v}^r_{25,c}$ (2)	$\underline{v}^r_{25,c}$ (20)	$\underline{v}^{rflex}_{25,c}$ (26)	$\underline{v}^r_{25,c}$ (20)	$\underline{v}^{rflex}_{25,c}$ (26)	$\bar{v}^r_{25,c}$	$\underline{v}^r_{25,c}$	$\underline{v}^{rflex}_{25,c}$	Thousand €	%
	[1]	[2]	[3]	[4]	[5] = [3]/[2]−1	[6] = [4]/[2]−1	[7] = [1]∗[2]	[8] = [1]∗[3]	[9] = [1]∗[4]	[10] = [9]−[8]	[11] = [9]/[8]−1
Andalusia	5,287,007	0.26649	0.29643	0.29691	11.234%	11.415%	1,408,939	1,567,218	1,569,771	2,553	0.163%
Aragón	1,364,103	0.25840	0.28790	0.28865	11.418%	11.709%	352,479	392,725	393,752	1,028	0.262%
Asturias, P. de	661,862	0.28010	0.30327	0.30399	8.271%	8.530%	185,387	200,721	201,201	480	0.239%
Balearic Islands	512,887	0.17084	0.17084	0.17099	0.000%	0.090%	87,621	87,621	87,700	79	0.090%
Canary Islands	756,766	0.26617	0.26617	0.26619	0.000%	0.008%	201,431	201,431	201,447	15	0.008%
Cantabria	953,615	0.18530	0.20150	0.20319	8.745%	9.658%	176,704	192,156	193,770	1,613	0.840%
Castilla y León	2,311,785	0.28409	0.30505	0.30517	7.380%	7.419%	656,750	705,220	705,477	257	0.036%
Castilla-La Mancha	2,891,832	0.22672	0.24920	0.25136	9.916%	10.868%	655,628	720,642	726,884	6,241	0.866%
Catalonia	7,567,571	0.24332	0.27055	0.27119	11.191%	11.455%	1,841,334	2,047,397	2,052,256	4,859	0.237%
Valencia	3,079,768	0.29177	0.31658	0.31695	8.504%	8.633%	898,570	974,988	976,145	1,157	0.119%
Extremadura	521,361	0.29811	0.33398	0.33434	12.033%	12.151%	155,425	174,127	174,311	184	0.106%
Galicia	1,734,584	0.24732	0.27872	0.27946	12.696%	12.993%	428,999	483,464	484,739	1,276	0.264%
Madrid	4,072,147	0.22749	0.25618	0.25635	12.612%	12.684%	926,377	1,043,210	1,043,879	669	0.064%
Murcia, R. de	1,457,678	0.28980	0.31718	0.31774	9.450%	9.642%	422,430	462,349	463,162	813	0.176%
Navarra, C.F. de	1,069,325	0.23824	0.25927	0.26018	8.827%	9.208%	254,757	277,246	278,215	969	0.350%
Basque Country	2,434,896	0.23672	0.25646	0.25766	8.340%	8.845%	576,388	624,456	627,371	2,915	0.467%
Rioja, La	274,988	0.25029	0.27900	0.27995	11.472%	11.849%	68,827	76,722	76,982	260	0.339%
Ceuta y Melilla	93,742	0.25134	0.25134	0.25152	0.000%	0.073%	23,561	23,561	23,578	17	0.073%
Extra-Regio											
National	**37,045,917**						**9,321,607**	**10,255,253**	**10,280,639**	**25,387**	**0.248%**

Source: Own elaboration.

Balearic Islands (79), Ceuta and Melilla (17) and the Canary Islands (15), where the innovation is not applied (i.e. $\bar{v}^r_{25,c} = \underline{v}^r_{25,c}$), the gains in productivity come from the lower price in *S*25, which originates from the relationships with the innovative regions (intermediate consumptions). In relative terms, the greatest growth in gross operating surplus is observed in Galicia, with Castilla y León ranking last amongst the innovative regions.

6. Conclusions

This paper extends and improves the approach outlined by Carter (1990) to assess the economy-wide benefits of innovations. She summed up her contribution (p. 256) writing "Hypothetical data are useful in examining and presenting the logic of the economic system, but the challenge lies in implementing the theoretical system with real data." We follow her suggestion by developing and implementing the model within an interregional input–output (IO) framework. We consider a disruptive innovation in the transport industry, one of the most relevant sectors in any economy in terms of intermediate (wholesale and retail) distribution and final consumption (i.e. transport of goods and passengers).

For the analysis we rely on a newly developed IO table for Spain that details the transportation sector in order to improve managerial decision-making and policy analysis. The innovation brings productivity gains in the form of cost savings in intermediate consumption and labour. These inputs savings are implemented in the form of lower technical coefficients. Solving then the proposed demand and price models applying the new coefficients allows us to determine who appropriates the benefits of innovation in the form of higher firm profits or lower consumer prices. Also, in the absence of spillovers, these benefits would be circumscribed to the innovative sector, but both sectoral and regional spillovers show that depending on the economic structure of the economy, some regions and sectors benefit more from these two forms of backward and forward linkages (i.e. spatial and industrial).

From an empirical perspective, we focus on a specific innovation in the sector of freight road transportation, associated with the adoption of longer and heavier vehicles known as road trains or megatrucks. Based on previous research by the authors, we employ an engineering approach to assess the savings that the authorization of these vehicles would have on the transport costs between regions. Translating these operational distance and time costs (corresponding to acquisition prices) to the national accountancy framework (in basic prices) is a very precise and demanding exercise. Ultimately, however, it allows us to modify the technical coefficients associated with all the cost items in the IO table; more specifically, those referring to fuel, labour and taxes, which are the main components of the cost structure of road transportation.

Subsequently, based on the demand and price models developed for the interregional IO table, we simulate the introduction of the new vehicle by replacing the initial vector of technical coefficients corresponding to the old technology with the new ones that characterize the innovation. Solving the interregional model for the Spanish case and selected innovation shows that the adoption of the new vehicle mainly benefits the road freight transportation sector in which the innovation takes place. Relying on the demand model we observe that the innovation reduces intermediate consumption, labour and taxes less subsidies in the sector by −1.64%, −8.04% and −6.98%, respectively, while increasing its gross value added by 2,00% and firm profits by 10%. However, these gains are not transferred to the rest of the economy when the fixed final demand assumption holds; i.e. gross operating surpluses and value-added remain basically constant for the rest of the economy. Allowing for a flexible/fixed price structure, from the perspective of the price model we observe that the LHVs sector will appropriate the benefits of the innovation. This finding comes as no surprise given the increasing concentration (both vertical – on own account – and horizontal – for hire or reward) that the adoption of the megatruck will bring to the specific market niches where LHVs operate. Nevertheless, we want to exert some caution about these results since they are obtained under the assumption that the market power of firms operating with LHVs increases. This conclusion hinges upon the existence evidence we have on the slow adoption rate of LHVs within the industry, currently driven by few large firms capable of reaping the benefits of the scale and distance economies that these vehicles offer. If adoption rates were to increase, resulting in a widespread presence of LHVs, however, this would increase effective competition, and then the appropriation of benefits that we report could only take place in the short run. Consequently, if the degree of competition increased in the long run, the benefits of the innovation would be distributed within the economic system through lower prices. Another relevant finding is that the benefits of the innovation within the road freight transportation sector are not necessarily higher in those regions with the largest sector but can also reach relevant values in other regions (spillovers) depending on their industrial and spatial linkages.

Although numerous additional analyses could be produced focusing on individual or a subset of variables, it depends on the particular focus and interest of the decision-maker and policy analyst. For this reason, we encourage the interested reader to implement their choice of innovation by adopting the methodological approach proposed here, within the (interregional) IO tables of interest. For example, a good case in the transportation sector would be currents trends in the adoption and diffusion of hybrid and electric vehicles at the expense of internal combustion engines, coupled with the necessary recharging infrastructure and regulatory legislation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Ministerio de Fomento, Spain: [Grant Number P42-08].

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