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A STRUCTURAL DECOMPOSITION ANALYSIS FOR TRAFFIC DEMAND ASSESSMENT ON A FREIGHT TRANSPORT CORRIDOR

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***Abstract**:*
This paper deals with a Structural Decomposition (SDA) applied to the analysis of the freight traffic demand in an Input Output (IO) modelling context. After reviewing the basic definitions of IO models and some methodological references for their application in the freight transport field, the paper proposes the application of the SDA in the perspective of a freight corridor. This application takes place downstream of an IO model that directly relates the quantities of goods transported along the corridor with the functioning of the reference economic system. Considering the evolution of tons annually transported in a certain time interval, the SDA model allows to isolate the specific effects related to: intensity of freight traffic typical of the corridor; technological structure of the production sectors; characteristics of the final demand in relation to its overall level, sectoral structure and allocation between components. The SDA model is applied to a case study considering the total volumes of goods annually in transit at the Brenner pass between 2000 and 2014. The evaluation of the polar forms of the multiplicative decomposition and their geometric mean allow to quantify the effects of each factor on the variation of the tonnage in terms of indexed value, absolute variation and percentage contribution compared to the base year (2000). The relative influences on freight traffic at the Brenner pass are therefore highlighted, both in terms of total volumes transited and impacts attributable to each of the decomposition factors introduced, with particular evidence also in the event of periods of economic and financial crisis. The SDA specified in the paper and the related case study provide useful elements for studying the traffic demand of goods through a freight corridor, helping in outlining the effects of the different driving forces related to the economic system and affecting freight transport demand trends.

Keywords: *freight traffic models, input-output model, freight corridor, structural decomposition analysis*

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1. Introduction

In recent decades, the modeling of commercial relations and, consequently, of goods flows has been widely studied, developing and applying SPatial Accounting Models (Tavasszy and De Jong, 2014), abbreviated SPAM. A first group of SPAM includes the Input-Output (IO) models (Leontief, 1986), (Miller and Blair, 2009), which represent the economy through a series of linear relationships between the productive and consumption sectors. The inter-industrial relations are expressed in terms of intermediate inputs between the different economic sectors (i.e. related to the different industrial sectors and including also inter-regional exchanges in the multi-regional versions), as an ex-post equilibrium between demand and supply. This equilibrium occurs under the hypothesis of constant prices and considering an exogenous final demand. A second group of SPAM includes the Computable General Equilibrium models (CGE) in the spatial (or regionalized) version (Spatial CGE - SCGE or Regional CGE - RCGE). A CGE or SCGE/RCGE model (Dixon and Jorgenson, 2012) (Burfisher, 2017) is formalized through a system of equations describing the whole economic system. These models synthetize the interactions between its parts, to make a supply and demand balance (and any concurrent economic factors) under a certain price level. The equations of the CGE model, deriving directly from the Economic Theory, can describe: the producers' supply; the consumers' demand; exogenous and endogenous variables; market compensation constraints. These equations are solved simultaneously (i.e. "Computable" meaning) to identify an economic equilibrium (i.e. "Equilibrium" meaning) in which under a certain price level, producers, consumers, workers and investors maximize their utility. The maximum utility relates to: the quantities of goods they produce and consume; the number of working hours; the amounts of capital that they save and invest. Thus, taking into account all the activities (i.e. "General" meaning) in the economic system (Burfisher, 2017). In the SCGE/RCGE models the economic equilibrium incorporates the distance between the economic agents (i.e. the transport cost), under a geographical point of view.

IO models have seen numerous applications, due to their simple structure that allows to clarify the interdependent relationships between economic sectors and geographical areas. Their implementation appears easier than CGE models, which show a more complex structure and require intensive and often hard-to-find datasets.

The analysis of transport systems is an important applicative context for the inter-sectorial economic analysis, especially regarding the transport of goods (Mauro and Pompigna, 2020). IO models can provide significant operational techniques and tools to assess the impacts by potential economic shocks on transport system and vice versa, supporting political decisions and planning actions for transport networks and infrastructures.

In the IO framework, an analytical approach known as Structural Decomposition Analysis, SDA, (Rose and Casler, 1996) (Miller and Blair, 2009) has been gradually developed over the years. The SDA method is formalized in economic analysis in the 1990s as a method for identifying the drivers of observed changes in an economic system, which is represented by an IO model (Rose and Casler, 1996) (Koppány, 2017) (de Boer and Rodrigues, 2020). SDA is closely related to Index Numbers Analysis (UNEC, 2004) and can be considered as the extension to IO models structure of the Index Decomposition Analysis (IDA) (de Boer and Rodrigues, 2020). In general terms, SDA consists in a factoring process, related to temporal changes or regional differences, of an economic phenomenon that can be examined with an IO model. In this perspective, the factoring components help to a greater understanding of the actual drivers of observed change and of their weights. In other words, the SDA method allows to assess the level of influence that the different variables that can be included in an IO model exert on the output of the same (e.g., in terms of variations over a given time period).

As a broadly economic analysis tool, with numerous applications including analysis of production, employment, value added or labor income, in recent years SDA has established itself as a tool for analyzing changes observed over time on energy and environmental variables (e.g., energy consumption and emissive factors of polluting or climate-altering gases). Different methods and applications are discussed, for example, by Miller and Blair (2009) and de Boer and Rodrigues (2020). Transportation applications of SDA, excluding analyses on energy consumption and emissions for transport activities in Lakshmanan and Han (1997), Lu et al. (2007),

Timilsina and Shrestha (2009) and Zhang et al. (2011), however, do not seem to have much evidence in literature. For some application examples, in particular regarding freight transport, we can indicate Alises et al. (2014) and Alises and Vassallo (2015; 2016). In these studies, SDA is configured as a task following an IO model for the macro-analysis of freight traffic demand: it allows to investigate the reasons for the misalignment (i.e. decoupling) between the evolution of the variables of the economic system and the variables of the transport system arisen in the last few years in some national contexts.
In this study, we use SDA to analyze the observed changes in the time series of total annual tons of goods passed through a freight corridor. Starting from the macro-approach to IO modeling by Pompigna and Mauro (2020), which directly relates the quantities of goods transported along a multimodal corridor with the functioning of the economic system, this work proposes an SDA application for the factorization of the effects exerted by the same economic system. SDA allows us to isolate the factors of the economic system that drive changes in the trend of the freight volumes (annual tons of goods transported), identifying the relative weight on the overall observed variation. In this way, with this study we add a third level of analysis to the two-level freight corridor model in Pompigna and Mauro (2020) applying a multiplicative SDA. The decomposition of the economic effects on freight traffic demand concerns in particular: the intensity of the freight traffic of the corridor; the technological level of the production sectors; the characteristics of the final demand, distinguishing it in turn according to its level, sectoral structure and components allocation. Also in this case, the SDA model is applied to a case study considering the total freight volumes (road-rail) annually in transit at the Brenner Pass and assuming the entire Italian national territory as the reference region for the IO model. The proposed SDA model has the versatility of a practice-ready approach (Pompigna and Rupi, 2018), useful for direct applications in the concerned sectors.
The paper is structured as follows. Section 2 defines the methodological framework by introducing the basic definitions of Input Output modeling and the extensions for its application to transport system analysis. A macro approach to traffic IO analysis for a freight corridor treated in the essential traits. From this IO framework, we formalize the SDA for the analysis of the factorization effects for the corridor during a given reference period. Section 3 shows a concrete application of the SDA model to the freight traffic demand at the Brenner Pass, a key Alpine pass straddling the border between Italy and Austria, discussing the results over a 15-year analysis period between 2000 and 2014. Finally, section 4 contains some concluding remarks.

2. The methodological framework

2.1. Input Output modeling and transport applications

An Input Output (IO) model describes the mutual relationships between the industrial sectors within a given region, the connections with industrial sectors outside the region itself and the interactions with the final internal and external demand for a given time interval. The regional transactions table, also called Input Output (IO) table, is the core of the model as it describes, in terms of monetary units, the mutual interrelations between the sectors of a given economic system and for a specific time interval (generally annual). Figure 1 shows a standard IO table. Each row identifies a production sector i of the economic system, with its sales towards each of the n regional industrial sectors represented by column (Industrial Consumption), as well as towards the final uses (Final Demand). Each column describes the value of the purchases of intermediate goods made by the sector j with respect to each of the n regional industrial sectors represented by row (Industrial Consumption), as well as the use of the primary factors (Payments).
The IO table in Figure 1 shows four quadrants (Schaffer, 1999): the Consumption Structure (I), i.e. sectorial consumption by families, investors, public administrations and external markets (export); the Production Structure (II), i.e. the ways in which intermediate goods are combined to produce goods; the Primary Uses (III), i.e. the payments for the primary factors (added value) and import; Social Transfers (IV), i.e. non-market transfers between the sectors of the economy (taxes/subsidies of families, surplus/deficits of administrations).
An IO table, however, represents an ex-post and descriptive summary of the economic system, i.e. a snapshot of a given region in a certain time interval. Because of its nature, it does not allow investigating the functioning of the economic system, e.g. to test

its reactions to possible changes. These aspects require some structures and relationships that complete the descriptive framework of the table, in other words they require an economic model expressed in mathematical terms.

At the end of the thirties of the last century Leontief developed an analytical tool with which it is possible to investigate the functioning of the economic system represented by the IO table. This is the Leontief's Input Output model, which will lead the author to the Nobel Prize for Economics in 1973. The Leontief's IO model is a simplified version of a general economic equilibrium model between supply and demand, aimed at the empirical study of the quantitative interdependence between the various economic sectors and activities under a perfect competition market hypothesis. The model is based on three types of relationships focused on the IO table information: basic identities; equilibrium conditions; technical conditions (Schaffer, 1999). The basic identities concern the production outputs and inputs for sectors, that is the sums of the components of the table respectively by row and by column. The technical conditions are represented by the intermediate resources distribution, i.e. the input usage scheme for the industrial production, through the technical coefficients matrix $\boldsymbol{A}$. The equilibrium conditions are dictated by the perfect competition market assumption with the ex-post equilibrium between supply and demand.

If $\boldsymbol{q}$ is the vector of the sectorial components of the production and $\boldsymbol{f}$ is the vector of the final demand, the matrix expression of the Leontief's IO model is:

$$\boldsymbol{q} = (\boldsymbol{I} - \boldsymbol{A})^{-1} \cdot \boldsymbol{f} = \boldsymbol{L} \cdot \boldsymbol{f} \tag{1}$$

where $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}$ is the so-called Leontief's inverse matrix. The existence and uniqueness of a positive solution for Equation (1) is guaranteed by the invertibility of $(\boldsymbol{I} - \boldsymbol{A})$ and the non-negativity of the terms of $\boldsymbol{L}$. These conditions represent in mathematical terms the "vitality" of the economic system, i.e. the capacity of each sector to generate an output higher than necessary as input for all sectors.

According to Equation (1), Leontief's model is demand driven as the final demand is the driving force of the whole economy. For this reason, in IO modeling the final demand components are identified exogenously, assuming that production supply components of the economic system adapt to them.

Under these hypotheses, if the conditions of a vital economic system are stable (constancy of technical coefficients in $\boldsymbol{A}$; invertibility of $(\boldsymbol{I} - \boldsymbol{A})$; non-negativity of the terms of $\boldsymbol{L}$), the model can be used to evaluate the impacts generated by a variation in the final demand $\boldsymbol{f}^*$ in terms of the production $\boldsymbol{q}^*$, being $\boldsymbol{q}^* = \boldsymbol{L} \cdot \boldsymbol{f}^*$.

Starting from the basic single region model (i.e. Single Region IO - SRIO), the necessity for transport applications to consider a geographical perspective (i.e. the exchanges between zones) has led to multiregional models, such as the Inter-Regional IO - IRIO (Isard, 1951) or the Multi-Regional IO - MRIO (Chenery, 1953) (Moses, 1955) models. These evolved IO structures introduce exchange or trade coefficients between a number of regions or sub-regions.

			INDUSTRIAL CONSUMPTION								FINAL DEMAND					TOTAL
			Agriculture	Mining	Constructions	Manufacturing	Trading	Transport	Services	Other sectors	Private Consuptions	Public Consumptions	Investments	Stock changes	Export	
PROCESS SECTORS	INDUSTRIAL PRODUCTION	Agriculture														
		Mining														
		Constructions														
		Manufacturing				***Inter-sectoral Production Structure* (II)**							***Consumption Structure* (I)**			***Total Use***
		Trading														
		Transport														
		Services														
		Other sectors														
PAYMENTS SECTORS	ADDED VALUE	Wages														
		Surplus														
		Fixed Capital				***Primary Uses* (III)**							***Social Transfers* (IV)**			
		Depreciations														
		Taxes														
	IMPORT	Import														
TOTAL							***Total Supply***									

Fig. 1. An exemplificative Input Output table

As a further evolution of the MRIO models, the so-called Random Utility-Based MRIO or RUBMRIO (Min et al. 2001), (Timmermans, 2003) (De la Barra, 1989), (Jin et al., 2003) (Cascetta et al, 2013), (Bachmann et al., 2014) models consider elastic trade coefficients based on random utility models. Thus, RUBMRIO models allow the representation of the feedback between the economic system and the transport systems, modeling the price elasticities and the trade coefficients as functions of the generalized transport costs (Cascetta et al., 2013). Other useful extensions for transport applications regard the temporal variability of the technical coefficients, with specific models that allow for a perspective of evolution of the production structure (Miller and Blair, 2009) (Bachmann et al., 2014). The basic model and the extensions mentioned above can be implemented in a single framework, i.e. a Decision Support System (DDS) (Cascetta et al., 2013) (Yu, 2018) (Mauro and Pompigna, 2020), integrating an IO model with a transport model and allowing to evaluate feedbacks between economic and transport systems. From this point of view, however, Mauro and Pompigna (2020) highlight the existence of real obstacles to the use of IO models – inherent with the complex articulation of modeling structures and the difficulty of obtaining the necessary data – as a concrete support for planning transport systems and infrastructures.

2.2. The macro approach to IO analysis of a freight traffic corridor

In the specific perspective of a freight corridor, Pompigna and Mauro (2020) propose a macro model that directly relates the quantities of goods transported with the functioning of the economic system, representing the latter by means of an IO model of the SRIO type, taking up the general approach of Alises and Vassallo (2016) and using the Freight Transport Intensity ratio (FTI) (Brunel, 2005) (McKinnon, 2007) (Kveiborg and Fosgerau, 2007) (Alises and Vassallo, 2016).

In general, the FTI can be expressed as the number of transport units necessary to produce a unit value of GDP (Brunel, 2005), or a unit value of production output (Åhman, 2004) (Alises and Vassallo, 2016) by the economic system in a certain region. The FTI can be disaggregated in sectoral terms, using the structure by production branches characteristic of the IO approach and it can be further expressed in representative values of each component of the whole transport system (e.g., road, rail, multimodal solutions, etc.). These values can be represented, for example, by the total distances per output unit (e.g. vehicles·km/euro for road transport, tons·km/euro for rail transport, etc.) or by the number of traffic units for output units (number of trains/euro in rail transport or equivalent transport units (TEU)/euro in combined transport, etc.).

Assuming to operate with a single mode of transport, or even for the entire freight transport system, and considering the n production sectors that characterize the economic system of a certain region, given the vector of sectorial outputs $\boldsymbol{q}$, we can identify the $\boldsymbol{FTI}$ vector of the FTI sector values according to the following definition:

$$\boldsymbol{FTI} = diag(\boldsymbol{q}^{-1}) \cdot \boldsymbol{T} \tag{2}$$

where $\boldsymbol{T}$ is the traffic vector whose components express the demand for freight transport relating to each production sector (e.g., vehicles*km, tons, etc.). Considering the fundamental relationship of Leontief (see Equation (1)), we can write (Alises and Vassallo, 2016) (Pompigna and Mauro, 2020):

$$\begin{aligned} \boldsymbol{T} = & \; diag((\boldsymbol{I} - \boldsymbol{A})^{-1} \cdot \boldsymbol{f}) \cdot \boldsymbol{FTI} = \\ = & \; diag(\boldsymbol{L} \cdot \boldsymbol{f}\,) \cdot \boldsymbol{FTI} \end{aligned} \tag{3}$$

Thus, the $\boldsymbol{FTI}$ vector allows the representation of freight traffic flows to be integrated into the general treatment of the IO model. If we know $\boldsymbol{FTI}$ and the inverse Leontief matrix $\boldsymbol{L}$ for a certain region in a given reference period, using Equation (3) it is possible to evaluate the effects of a variation of the final demand $\boldsymbol{f}$ on the transport demand $\boldsymbol{T}$. The sectoral components of $\boldsymbol{FTI}$ can be known directly, deriving from specific surveys, or can be estimated by means of a chain of factors (Alises and Vassallo, 2016).

2.3. The application of Structural Decomposition Analysis

The IO model synthesized with Equation (3) can be specified for a generic year t, in the following way:

$$\boldsymbol{T}_t = diag(\boldsymbol{L}_t \boldsymbol{f}_t)\boldsymbol{FTI}_t \tag{4}$$

Equation (4) can be used to evaluate the effects generated over the years by changes in the economic system on the annual variation of freight traffic resorting to a SDA approach (Rose and Casler, 1996) (Miller and Blair, 2009).

In the simplest form of the IO model expressed by the equation $\mathbf{q}_t = \mathbf{L}_t \mathbf{f}_t$ over a certain time interval between 0 and t, SDA allows to evaluate the effects on the production variation $\Delta \boldsymbol{q}_t = \boldsymbol{q}_t - \boldsymbol{q}_0$ due to changes in the Leontief matrix $\Delta \boldsymbol{L}_t$ and in the final demand $\Delta \boldsymbol{f}_t$. With an increasing analysis detail of the decomposition, we can include further variables to isolate, as regards the final demand, the effects of the variation of its sectoral distribution or those related to its breakdown into the final consumption, investment and export shares.
Taking into account the IO model represented by equation (4), with reference to the total of the tons transported T_t in place of the vector $\boldsymbol{T_t}$, the basic IO model for the generic year t consists of:

$$T_t = \boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{f}_t) \quad (5)$$

The structural decomposition concerns the second member of Equation (8), in which a first term linked to the specific effect of the freight traffic intensity (i.e. the total quantity of tons transported per unit of output) is represented by $\boldsymbol{FTI'}_t$, a row vector of dimension n. In addition, the term relating to the total production represented by $\boldsymbol{L}_t \boldsymbol{f}_t$ can be decomposed into four further factors relating to:

- technological effect, given by the structure of the Leontief matrix $\boldsymbol{L_t}$ which returns the amount of inputs necessary to produce the outputs in the economic system;
- effect of the sectoral structure of the final demand, given by the distribution of the same final demand among the sectors and expressed by means of the matrix $\boldsymbol{S_t}$ (whose dimensions are $n \cdot d$, where n is the number of industrial sectors and d is the number of categories for the final demand). This matrix represents the distribution of each category of final demand (e.g. final consumption, investments, and exports) with respect to the various industrial sectors;
- effect of the allocation of the overall final demand f_t, given by the distribution of the total final demand among its categories (e.g. final consumption, investments, and exports) and expressed by means of a vector $\boldsymbol{D_t}$ (whose dimensions are $d \cdot 1$, where d is the number of categories for the final demand);
- effect of the level of the final demand f_t, which indicates the overall level of final demand as the sum of the components of the vector $\boldsymbol{f_t}$.

In consideration of the factors identified above, Equation (5) can be expressed as:

$$T_t = \boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S_t} \boldsymbol{D_t} f_t) \quad (6)$$

The changes in the tons transported within a time interval $[0, t]$ can be expressed based on the following ratio ΔT_t:

$$\Delta T_t = \frac{T_t}{T_0} = \frac{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S_t} \boldsymbol{D_t} f_t)}{\boldsymbol{FTI'}_0(\boldsymbol{L}_0 \boldsymbol{S_0} \boldsymbol{D_0} f_0)} \quad (7)$$

As regards SDA, expressed in this case in the multiplicative form according to Equation (7), it should be noted that the decomposition components do not necessarily represent the actual causes of the variations. We can consider these factors as weighted measures of the variations. In any case, if such causality really exists, the determining factors may not be independent or the decomposition may not reach the root causes, or two or more factors in the decomposition may have a common determinant not included in the model (and potentially not even observed) (Koppány, 2017).
The SDA methodology used in this study for the model expressed according to Equation (7) is of the type formalized by Dietzenbacher and Los (1998) and widely used in literature. This decomposition form, often identified as D&L decomposition, is preferred to other approaches when, as in this case, we are dealing with 5 or more factors (Su and Ang, 2012). According to Dietzenbacher and Los (1998) an expression of the type of Equation (7) admits the following 5-factor multiplicative decomposition:

$$\begin{aligned}\Delta T_t &= \frac{\boldsymbol{FTI'}_t(\boldsymbol{L}_0 \boldsymbol{S}_0 \boldsymbol{D}_0 f_0)}{\boldsymbol{FTI'}_0(\boldsymbol{L}_0 \boldsymbol{S}_0 \boldsymbol{D}_0 f_0)} \cdot \\ &\cdot \frac{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S}_0 \boldsymbol{D}_0 f_0)}{\boldsymbol{FTI'}_t(\boldsymbol{L}_0 \boldsymbol{S}_0 \boldsymbol{D}_0 f_0)} \cdot \frac{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S}_t \boldsymbol{D}_0 f_0)}{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S}_0 \boldsymbol{D}_0 f_0)} \cdot \\ &\cdot \frac{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S}_t \boldsymbol{D}_t f_0)}{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S}_t \boldsymbol{D}_0 f_0)} \cdot \frac{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S}_t \boldsymbol{D}_t f_t)}{\boldsymbol{FTI'}_t(\boldsymbol{L}_t \boldsymbol{S}_t \boldsymbol{D}_t f_0)} \cdot \\ &= \Delta FTI'^0 \cdot \Delta L^0 \cdot \Delta S^0 \cdot \Delta D^0 \cdot \Delta f^0\end{aligned} \quad (8)$$

According to Dietzenbacher and Los (1998), Equation (8) is only one of the many possible ways to decompose Equation (7), whose number is equal to the total permutations generated by the number of factors involved. In this case, with 5 factors, the number of the total forms of decomposition is equal to

5! = 120. The D&L method approximates the average value of all the possible decompositions with the average value of the two polar decompositions. The two polar decompositions are those that have no common terms.

Considering the first polar decomposition in the form of Equation (8) as expressed with respect to time 0, the second polar decomposition expressed with respect to t is constituted by:

$$\begin{aligned}\Delta T_t = & \frac{\boldsymbol{FTI'}_t(\boldsymbol{L}_t\boldsymbol{S}_t\boldsymbol{D}_t f_t)}{\boldsymbol{FTI'}_0(\boldsymbol{L}_t\boldsymbol{S}_t\boldsymbol{D}_t f_t)}\cdot \\ & \cdot\frac{\boldsymbol{FTI'}_0(\boldsymbol{L}_t\boldsymbol{S}_t\boldsymbol{D}_t f_t)}{\boldsymbol{FTI'}_0(\boldsymbol{L}_0\boldsymbol{S}_t\boldsymbol{D}_t f_t)}\cdot\frac{\boldsymbol{FTI'}_0(\boldsymbol{L}_0\boldsymbol{S}_t\boldsymbol{D}_t f_t)}{\boldsymbol{FTI'}_0(\boldsymbol{L}_0\boldsymbol{S}_0\boldsymbol{D}_t f_t)}\cdot \\ & \cdot\frac{\boldsymbol{FTI'}_0(\boldsymbol{L}_0\boldsymbol{S}_0\boldsymbol{D}_t f_t)}{\boldsymbol{FTI'}_0(\boldsymbol{L}_0\boldsymbol{S}_0\boldsymbol{D}_0 f_t)}\cdot\frac{\boldsymbol{FTI'}_0(\boldsymbol{L}_0\boldsymbol{S}_0\boldsymbol{D}_0 f_t)}{\boldsymbol{FTI'}_0(\boldsymbol{L}_0\boldsymbol{S}_0\boldsymbol{D}_0 f_0)}\cdot \\ & = \Delta FTI'^t\cdot\Delta L^t\cdot\Delta S^t\cdot\Delta D^t\cdot\Delta f^t\end{aligned} \tag{9}$$

The results of the multiplicative decomposition can then be calculated with the following equation:

$$\Delta T_t = \Delta FTI'\cdot\Delta L\cdot\Delta S\cdot\Delta D\cdot\Delta f \tag{10}$$

where each term of decomposition, representing the variation related to each of the 5 coefficients, is the geometric mean of the corresponding terms in the polar decompositions of Equations (8) and (9), that is:

$$\Delta FTI' = \sqrt{\Delta FTI'^0\cdot\Delta FTI'^t} \tag{11}$$

$$\Delta L = \sqrt{\Delta L^0\cdot\Delta L^t} \tag{12}$$

$$\Delta S = \sqrt{\Delta S^0\cdot\Delta S^t} \tag{13}$$

$$\Delta D = \sqrt{\Delta D^0\cdot\Delta D^t} \tag{14}$$

$$\Delta f = \sqrt{\Delta f^0\cdot\Delta f^t} \tag{15}$$

Equation (10), whose terms are defined by Equations (11) - (15) and calculated using the formalization of polar Equations (8) and (9), allows to evaluate the different effects on the variation $\Delta\mathrm{T}_t$ of the total tonnage between the base year 0 and target year t, linked to the variation of: the freight traffic intensity at the Brenner pass ΔFTI; production technologies, through ΔL; the sectoral structure of the final demand, through ΔS; final demand allocation into its categories, through ΔD; total final demand level Δf.

The contributions highlighted by the decomposition for each of the factors considered can be positive or negative, depending on the increasing or decreasing effect attributable to the single factor. The same impacts, as well as the index numbers with respect to the base year 0, can also be expressed in absolute terms. In this case, the effects can be expressed in terms of variation of annual tons between the target year and the reference year attributable to the single decomposition factor. The contributions of each decomposition factor can also be expressed as a percentage of the change in total tons using the following relationship:

$$p_K = \frac{\Delta K}{|\Delta FTI'| + |\Delta L| + |\Delta S| + |\Delta D| + |\Delta \boldsymbol{L}|} \tag{16}$$

where K indicates each decomposition factor. The sign of p_K is in accordance with that of the variation ΔK of the corresponding factor, as the direction of its effect on ΔT.

3. Model specification - The Brenner Pass and the basic data for the freight corridor model

The Brenner pass is namely the part of the Munich-Verona corridor crossing borders between Italy and Austria. The Brenner Pass is currently the most intensely trafficked pass in the entire Italian Alpine region, characterized by the presence of: an ordinary road infrastructure (Brennerstrasse B 182 on the Austrian side and SS12 del Brennero on the Italian side); a motorway infrastructure (A13 Brenner Autobahn on the Austrian side and A22 Autostrada del Brennero on the Italian side); a railway infrastructure (Brennerbahn Innsbruck / Brenner on the Austrian side and Ferrovia Brennero / Verona on the Italian side).

Over the years, regional, national and European policies have identified measures aimed at transferring significant amounts of freight traffic from road to rail (Nocera et al., 2018), especially to promote the attractiveness of rail transport and push towards a modal transfer from motorway. Among the interventions, the construction of the Brenner Base Tunnel - Brenner Basistunnel (BBT) stands out greatly. In very recent times, new studies have dealt with the subject, proposing updated forecasts of the total annual tonnages of goods transported by road + rail and the modal split between the two coexisting transport systems, using time logistic trend analysis

(Mauro and Cattani, 2018), time series analysis with dynamic components (Mauro and Pompigna, 2019) and Input/Output models (Pompigna and Mauro, 2020).

As in Pompigna and Mauro (2020), for the application of the model in Equation (4), we have considered the Input Output tables for Italy in the WIOD 2016 database (Timmer et al., 2015), extracted according to the ISIC Rev. 4 56-sector classification for each year between 2000 and 2014 (millions of US dollars, current year prices and previous year price). These IO tables were recalculated in millions of euro and constant prices at base year 2000 and reclassified in the following 9 sectors: A - agriculture, hunting, fishing and forestry; B - food, drink and tobacco; C - mining and construction; D - textile; E - energy, fuel and energy products, waste; F - chemical products; G - transport machinery and equipment; H - manufactured products; I - services. On the basis of these reclassified IO tables, we calculated the technical coefficients matrices $\boldsymbol{A}_t$ and the inverse Leontief matrices $\boldsymbol{L}_t = (\boldsymbol{I} - \boldsymbol{A}_t)^{-1}$, the production vectors $\boldsymbol{q}_t$ and the final demand vectors $\boldsymbol{f}_t$, for each year t between 2000 and 2014.

For the freight demand characterization, we considered the total tonnages crossing the Brenner pass in the interval 2000-2014 as reported in (MT, 2018). Table 1 shows the time series of the tons of goods transported annually, as a sum of road and rail values. Figure 2 shows, as index numbers with base year 2000, the trends of the components of $\boldsymbol{FTI}_t$. The trend shows a growth over the 15 years for values relating to: food, beverages and tobacco; manufactured products; energy, fuel and energy products; chemical products. A reduction appears, instead, for: machinery and transport equipment; agriculture, hunting, fishing and forestry; textile; extraction and construction.

4. Model results

In the case study, the SDA was conducted using the databases and information available, considering a fix base year 0 in 2000 and varying the target year t between 2001 and 2014. All the analysis considered constant prices with base year 2000.

Table 2 and Figure 3 show the decomposition value for each factor according to Equation (10) with varying the target year. Table 3 presents the p_K values according to Equation (15), while Table 4 and Figure 4 show the traffic changes in millions of tons per year as the contribution (increase or reduction) attributable to each decomposition factor.

Table 1. Time series of total tonnages between 2000 and 2014

Year	Total tons of goods (million tons/year)
2000	34.1
2001	35.8
2002	36.3
2003	37.7
2004	41.2
2005	41.7
2006	44.9
2007	48.3
2008	47.8
2009	38.9
2010	41.9
2011	42.3
2012	40.7
2013	40.7
2014	42.1

Source: (MT, 2018)

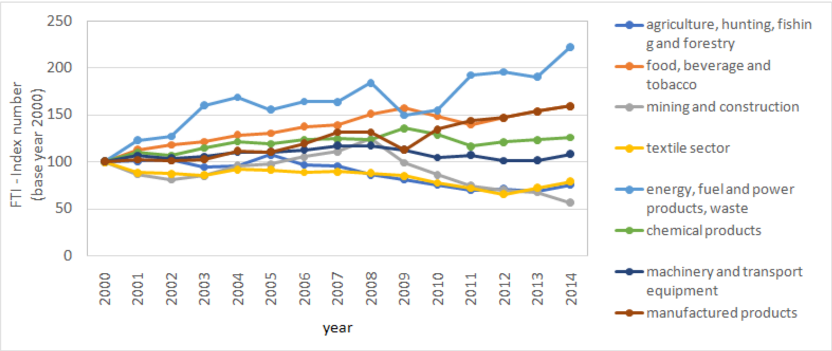

Fig. 2. Time evolution for FTI Index number by sector (base year 2000) at Brenner pass between 2000 and 2014

Table 2. SDA results - ΔK values from 2001 to 2014 with base year 2000

t	ΔT_t	ΔFTI	ΔL	ΔS	ΔD	Δf
2001	1.049853	1.057166	0.990571	0.984637	1.002244	1.015898
2002	1.064516	1.049923	1.000562	0.990902	1.003507	1.019060
2003	1.105572	1.093392	0.998619	0.989592	1.002610	1.020524
2004	1.208211	1.163539	0.993048	0.994588	1.009537	1.041420
2005	1.222874	1.162606	0.988073	0.994869	1.014192	1.055052
2006	1.316716	1.210973	0.980546	0.994639	1.026519	1.086070
2007	1.416422	1.262475	0.979748	0.997406	1.033889	1.110478
2008	1.401760	1.287773	0.973234	0.996771	1.027165	1.092399
2009	1.140762	1.219174	0.964194	0.965906	0.993842	1.010911
2010	1.228739	1.241103	1.024053	0.922070	1.017347	1.030614
2011	1.240469	1.247127	1.014251	0.916517	1.027131	1.041749
2012	1.193548	1.263247	1.005184	0.908345	1.027510	1.007092
2013	1.193548	1.290313	0.978101	0.922517	1.028675	0.996572
2014	1.234604	1.351135	0.975237	0.913804	1.031383	0.994136

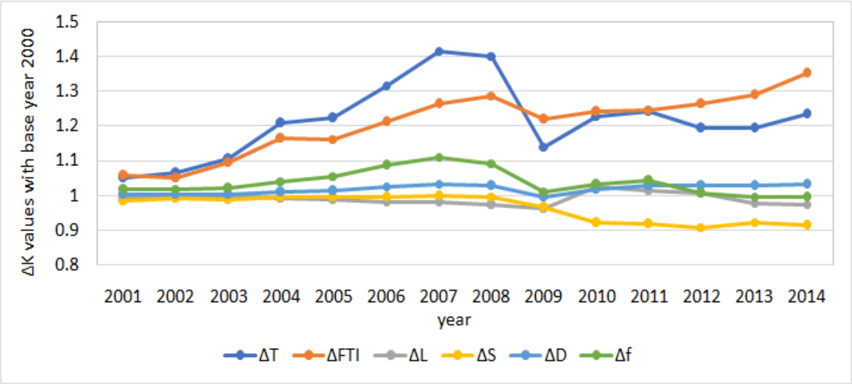

Fig. 3. SDA results - ΔK values from 2001 to 2014 with base year 2000

Table 3. SDA results - p_k values from 2001 to 2014 with base year 2000

t	$p_{\Delta T_t}$	$p_{\Delta FTI}$	$p_{\Delta L}$	$p_{\Delta S}$	$p_{\Delta D}$	$p_{\Delta f}$
2001	100%	113%	-19%	-30%	4%	31%
2002	100%	78%	1%	-14%	5%	30%
2003	100%	89%	-1%	-10%	2%	20%
2004	100%	81%	-3%	-3%	5%	20%
2005	100%	76%	-6%	-2%	7%	26%
2006	100%	71%	-7%	-2%	9%	29%
2007	100%	68%	-5%	-1%	9%	29%
2008	100%	76%	-7%	-1%	7%	24%
2009	100%	142%	-23%	-22%	-4%	7%
2010	100%	103%	10%	-33%	7%	13%
2011	100%	100%	6%	-34%	11%	17%
2012	100%	125%	2%	-43%	13%	3%
2013	100%	134%	-10%	-36%	13%	-2%
2014	100%	132%	-9%	-32%	12%	-2%

Table 4. SDA results - Net difference in total annual tonnage changes referred to 2000 and contribution of decomposition factors (millions of tons per year)

t	ΔT_t	ΔFTI	ΔL	ΔS	ΔD	Δf
2001	1.700	1.924	-0.317	-0.517	0.076	0.535
2002	2.200	1.717	0.019	-0.313	0.121	0.656
2003	3.600	3.210	-0.047	-0.358	0.090	0.705
2004	7.100	5.744	-0.244	-0.190	0.335	1.455
2005	7.600	5.753	-0.422	-0.182	0.502	1.948
2006	10.800	7.627	-0.703	-0.194	0.959	3.112
2007	14.200	9.706	-0.749	-0.096	1.253	4.085
2008	13.700	10.448	-0.972	-0.117	0.986	3.355
2009	4.800	6.830	-1.116	-1.062	-0.192	0.340
2010	7.800	7.996	0.798	-2.585	0.575	1.015
2011	8.200	8.212	0.474	-2.774	0.902	1.387
2012	6.600	8.220	0.162	-2.862	0.859	0.221
2013	6.600	8.863	-0.669	-2.366	0.875	-0.105
2014	8.000	10.573	-0.746	-2.595	0.945	-0.177

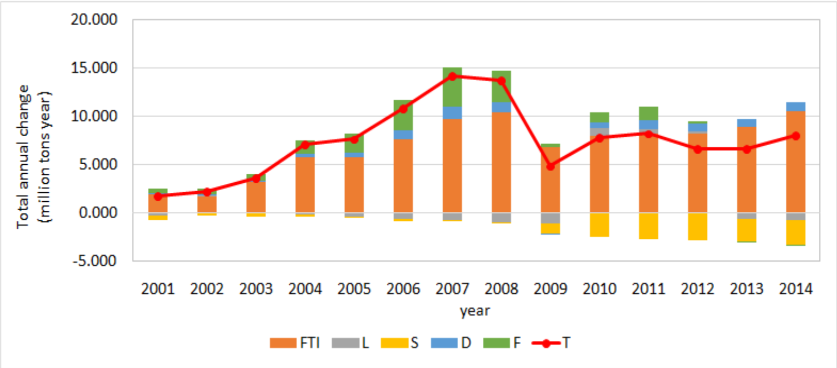

Fig. 4. SDA results - Net difference in total annual tonnage changes referred to 2000 and contribution of decomposition factors (millions of tons per year)

5. Discussion and conclusions

The numerical results of the SDA presented in section 4 show a dominant effect for ΔFTI. The freight traffic intensity trend for the Brenner pass denotes a constantly rising influence, with a specific effect on the total of the goods transported which exceeds its actual increase since 2009 (cf. Table 2). The percentage weight $p_{\Delta FTI}$ (cf. Table 3) shows an increasing trend over the years, with values below 100% up to 2008 and exceeding 135% in recent years. As of 2014, the effect attributable to FTI returns an increase of 10.6 million tons compared to 2000 (i.e. the base year), against an actual traffic increase of 8 million tons (cf. Table 4).

The contribution to changes in the total annual tonnage compared to the base year attributable to the technological changes (i.e., the inter-sectorial productive scheme, represented by ΔL) shows an increasing reductive effect against ΔT_t up to 2009, highlighting an increasing technological efficiency of the whole economic system. However, starting from 2010, technological changes have influenced positively the freight traffic changes until 2012 (cf. Table 2). This occurrence indicates a temporary raise in intermediate transfers of goods between sectors, that is a drop-in production efficiency in the years immediately following the economic and financial crisis. This phenomenon reversed again in the years 2013 and 2014. In the last years, in fact, the ΔL effect is still of contraction, with a weight compared to the total of approximately -10% (cf. Table 3). In 2014, the effect attributable to technological changes in the economic system returned a reduction of 0.75 million tons compared to the base year (cf. Table 4).

In a parallel way with the effect shown for ΔFTI, the one relating to the sectoral distribution of the final demand, i.e. ΔS, emerges. Its values are substantially stable up to 2008, with a decreasing trend starting from 2009 (cf. Table 2). From 2009 onwards, the changes recorded in the final demand distribution between the sectors contract the freight traffic demand at the Brenner pass with a decidedly more weight compared to the previous period and exceeding 30% (cf. Table 3). As for 2014, the effect attributable to the sectoral structure of the final demand returns a reduction of 2.6 million tons compared to 2000 (cf. Table 4).

The effect related to the allocation of the final demand with respect to the categories that make it up (final consumption, investments and export) represented by ΔD highlights a positive and growing impact (except for the year 2009) on the changes in total transported tons at the pass (cf. Table 2). The weights of ΔD over the total changes show themselves growing and exceed 10% in recent years (cf. Table 3). As for 2014, the effect attributable to final consumption-investments-export allocation of the final demand returns an increase of 0.95 million tons compared to 2000 (cf. Table 4).

Finally, the effect related to the level of final demand represented by Δf proves to act as a net increase towards the demand for freight traffic in the whole period between 2001 and 2011 (cf. Table 2). This factor of the SDA therefore acts as an increase factor in the delta of the tons transported ΔT_t. The weight of the change attributable to Δf compared to the total is between 20% and 30% in the period before 2008, undergoing a contraction of up to 7% in 2009 and picking up some points in the following two years up to 17% in 2011. A new reduction is evident in 2012, with a weight on the total which stands at 3% (cf. Table 3). In the last two years of analysis, Δf emerges as a contractive factor for ΔT_t, due to the contraction of the final demand registered in the last two years 2013 and 2014 compared to the 2000 value. As for 2014, the effect attributable to the whole final demand level returns a reduction of 0.18 million tons compared to 2000 (cf. Table 4).

Taking into consideration the SDA results for 2014, i.e. the last year for IO time series for the specification of the corridor model, the effects that the decomposition factors have in explaining the increase of freight traffic demand at the Brenner pass (+ 23.5%, which corresponds to 8 million tons) can be summarized as follows:

- effect of the changes in the freight traffic intensity at the pass: 1.351, equal to 132% of the total change in freight traffic demand, with an increase contribution of 10.573 million tons compared to 2000;
- effect of technological changes in the productive structure: 0.975, equal to -9% of the total change in freight traffic demand, with a reduction contribution of 0.746 million tons compared to 2000;
- effect of the changes in the sectoral structure of the final demand: 0.914, equal to -32% of the total change in freight traffic demand, with a reduction contribution of 2,595 million tons compared to 2000;
- effect of the changes in the allocation of the final demand: 1,031, equal to 12% of the total change in freight traffic demand, with an increase contribution of 0.945 million tons compared to 2000;
- effect of the changes in the level of the final demand: 0.994, equal to -2% of the total change in freight traffic demand, with a reduction contribution of 0.177 million tons compared to 2000.

The increase in tons transited at the Brenner pass between 2000 and 2014 can therefore be explained in a preponderant way with the increase in its freight traffic intensity, corresponding to a net increase in the attractiveness of goods exchanges on the same corridor.

The technological changes interpreted by the variations of the Leontief matrix show a reduction effect due, essentially, to the increasing efficiency of production technologies and the consequent lowering of intermediate exchanges between sectors. A reduction effect also emerges for the sectoral structure of the final demand, due to a shift in demand shares on the sectoral grouping not primarily impacting on freight traffic and represented by the services sector. In addition, it can be noted that the SDA for the entire period 2001-2014 with base year 2000 clearly shows for all factors the presence of points of change

of the relative effects in the years at the turn of 2009, in correspondence with the economic crisis that occurred in international markets. The use of SDA allows us to highlight, therefore, how this crisis heavily affected traffic on the Brenner in the period in which it occurred, both in terms of total volumes transited and influences attributable to each of the decomposition factors.
In conclusion, the SDA model defined in this paper demonstrates its usefulness in the analysis of freight traffic corridor, as concretely showed by the application to the Brenner case study. SDA, in fact, proposes an effective and agile investigation tool, based on historical economic and transport data that are sufficiently easy to find and to handle. Its application, conjugated with a macro approach to IO modeling, provides useful elements for studying the traffic demand of goods through a freight corridor, helping in outlining the effects of the different driving forces related to the economic system and affecting freight transport demand trends.

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