

# INPUT/OUTPUT MODELS FOR FREIGHT TRANSPORT DEMAND: A MACRO APPROACH TO TRAFFIC ANALYSIS FOR A FREIGHT CORRIDOR

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## Abstract:

Input Output model are of great interest in the transport sector, especially regarding freight transport demand. These models allow to analyze the cross effects of: political, macroeconomic and transport changes; industrial dynamics; exchange flows between different sites within a reference area, more or less divided into sub-areas. Although very interesting and desirable to be used and disseminated, their use is often hindered by the complexity of the modelling structures that need to describe the interactions with the transport systems and by the difficulty of finding complete and reliable data. In this context, this paper deals with a macro-level Input Output approach for freight demand analysis, which directly relates the quantities of goods transported along a multimodal corridor to the functioning of the economic system. The proposed model is structured on two levels: the first level allows the sectoral production forecasts of the entire economic system based on the exogenous final demand; the second allows the forecast of tons transported, annually and by sector, along the corridor based on the sectoral production estimated at the first level. The two modelling levels are applied to the analysis and forecast of freight traffic demand along the Italian-Austrian cross-border stretch of the Brenner corridor, a fundamental axis of the European transport infrastructure network. The model has been verified and validated on data covering 15 years between 2000 and 2014 using the reclassified time series of Input Output tables and the international trade data for Italy. The model has been used to produce medium-long term forecasts for different economic scenarios. The macro-level point of view and the application for the corridor provide a simple and directly applicable model compared to the complex articulations that characterize the Input Output applications to the transport systems, which can hinder their concrete use as decision support in the planning of transport infrastructures.

**Keywords:** freight traffic models, Input-Output model, freight corridor, freight transport intensity

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## 1. Introduction

Early models for freight traffic analysis and forecasting were developed in the early 60s of the last century, substantially parallel to passenger transport models (Tavasszy & De Jong, 2014). Compared with the latter, their historical evolution has been much slower and often limited to simplistic applications of passenger traffic theories. The reasons for these circumstances are attributable to a multiplicity of factors, such as the lack of systematic and reliable data or the insufficient attention by political and administrative decision makers that have characterized freight transport in the past.

Over time, the focus on freight transport has gradually increased due to the growing volume of goods transported. This happened because of the increasing levels of consumption, moving towards an optimization in production and distribution strategies and a competitive use of different transport systems. In recent decades, the modelling of transport and trade relations, and consequently of goods flows, has been studied extensively by developing and applying transportation market shares models (Krata, 2010), transportation supply chain models (Pyza, 2011) and spatial accounting models (Tavasszy & De Jong, 2014).

In particular, this paper examines the Input Output (IO) models (Leontief, 1936) (Leontief, 1966) (Leontief, 1941) (Miller & Blair, 2009) that have characterized various applications in the transport sector over the years, especially regarding the freight sector (Yu, 2018). These models allow to analyze the cross effects of: political, macroeconomic and transport changes; industrial dynamics; exchange flows between different sites within a reference area. Their implementation also allows to formulate forecasts about future scenarios.

IO models represent the economy through a series of linear relations between the productive and consumption sectors, describing inter-industrial relations in terms of intermediate inputs between the different economic sectors and regions. Transport systems analysis opens an important perspective on the existing interdependencies within the sectors of an economic system. Understanding the role of transport systems in regional economic development represents a primary interest of applied research on regional and transport economics sectors (Lakshmanan, 2011). The IO approach makes possible the

identification and description of the transport systems connections with the inputs - outputs of the productive sectors, in considering the interdependence of industrial sectors within an economic system (Lee & Yoo, 2016). Based on the expression of inter-sectoral multiplier effects, the IO model allows us to describe the effects on the transport system caused by shocks in the economic system, both from a theoretical and an application point of view. In light of these considerations, IO models can support planning decisions for mobility infrastructures.

In this paper, the IO framework considers an aggregate level for freight transport demand, i.e. following a macro-type vision (Alises & Vassallo, 2016), and directly relates the quantities of goods transported along a freight infrastructure corridor with the operation of the economic system. The proposed model is structured on two levels: the first level allows the sectoral production forecasts of the entire economic system driven by the exogenous final demand, on the basis of the inter-sectoral relations in the production processes; the second allows the forecast of tons of goods transported annually and by sector along the corridor on the basis of the sectoral production estimated at the first level, depending on sectoral parameters of traffic intensity. These two levels are applied to the analysis and forecasting of freight traffic demand on one of the main European corridors for freight transport, that is the Brenner corridor, and in particular to the cross-border alpine pass between Italy and Austria. Through the elaboration of time series of Input Output tables for Italy, the model is validated and then used to formulate forecasts for different future scenarios.

The paper is structured as follows. Section 2 provides a brief overview of the basic concepts of IO modelling and of the main extensions related to freight transport. Then, the macro level approach is introduced, which relates the quantities of goods transported along an infrastructural corridor with the functioning of the reference economic system. Section 3 proposes the elements for the specification of the IO model in the case study, presenting some general features of the Brenner corridor and analyzing the data used for the analysis. Some aspects related to the "on sample" predictive capabilities of the model are then discussed, in relation to the degree of reliability of its results on the short (year on year) and medium-long period. Section 4 proposes an "out of sample" validation of the model through short-

term forecasts. Then, medium-long term forecasting application is presented, in consideration of three evolving scenarios for the economic system. Finally, section 5 proposes some conclusive considerations.

## 2. The methodological framework

### 2.1. The basics of Input Output modelling

An Input Output (IO) model allows us to describe the connections among the industrial sectors of a given region, the relations with industrial sectors outside the region itself and the interactions with the final demand. The central element of an IO model is the regional transactions table (Figure 1), also called Input Output (IO) table, which describes, in monetary units and for a specific time interval, the mutual interrelations that occur between sectors of a given economic system. Therefore, this accounting scheme provides an ex-post description of the economic system of a given region in a certain time interval. Without analytical content, in fact, it does not allow to investigate the functioning of the same economic system, with the intention of evaluating, for example, the ways in which it reacts to possible changes. These analysis require a real economic model with mathematical relations, capable of completing analytically the description provided by the IO table.

The IO model developed by Leontief at the end of the 1930s (Leontief, 1936) (Leontief, 1941), as is well known, constitutes the analytical tool with which we can represent and investigate the functioning of the economic system represented by the IO table. This model, for which Leontief received the Nobel Prize in Economics in 1973, appears as a simplified version of a general economic equilibrium, aimed at the empirical study of quantitative interdependence between the various economic activities in a context of perfect competition (Leontief, 1966).

The model is based on three relations types (Schaffer, 1999): basic identities or definitions; equilibrium conditions; technical conditions. The basic definitions of the model concern the sectoral outputs and production inputs (i.e., respectively sum by row and by column of the IO table elements). The technical conditions are represented by the scheme of intermediate resources usage (i.e., the distribution of inputs in the sectoral industrial production) through the so-called matrix of technical coefficients  $A$ . The conditions of equilibrium are dictated by the assumption of the perfect competition, with the achievement of the ex-post balance between demand and supply in the economic system.

|                  |                       | INDUSTRIAL CONSUMPTION      |  |               |               |         |           |                     |               | FINAL DEMAND         |                              |             |               |        | TOTAL            |  |
|------------------|-----------------------|-----------------------------|--|---------------|---------------|---------|-----------|---------------------|---------------|----------------------|------------------------------|-------------|---------------|--------|------------------|--|
|                  |                       | Agriculture                 | Mining                                     | Constructions | Manufacturing | Trading | Transport | Services            | Other sectors | Private Consumptions | Public Consumptions          | Investments | Stock changes | Export |                  |  |
| PROCESS SECTORS  | INDUSTRIAL PRODUCTION | Agriculture                 |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Mining                      |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Constructions               |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Manufacturing               | <b>Inter-sectoral Production Structure</b> |               |               |         |           |                     |               |                      | <b>Consumption Structure</b> |             |               |        |                  |  |
|                  |                       | Trading                     |  |               |               |         | (II)      |                     |               |                      |                              |             | (I)           |        |                  |  |
|                  |                       | Transport                   |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Services                    |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Other sectors               |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
| PAYMENTS SECTORS | ADDED VALUE           | Wages                       |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Surplus                     |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Fixed Capital Depreciations |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       | Taxes                       |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  | IMPORT                | Import                      |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
| <b>TOTAL</b>     |                       |                             |  |               |               |         |           |                     |               |                      |                              |             |               |        |                  |  |
|                  |                       |                             |  |               |               |         |           | <b>Total Supply</b> |               |                      |                              |             |               |        |                  |  |
|                  |                       |                             |  |               |               |         |           |                     |               |                      |                              |             |               |        | <b>Total Use</b> |  |

Fig. 1. Basic structure of an Input - Output table

If  $\mathbf{q}$  is the vector of the production and  $\mathbf{f}$  is the vector of the final demand, both expressed with components relating to each of the  $N$  productive sectors that characterize the economic system, the IO model appears in the following well-known expression:

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

where  $\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-1}$  is the so-called Leontief inverse matrix. The existence and uniqueness of a positive solution for the system (1) is guaranteed by the invertibility of  $(\mathbf{I} - \mathbf{A})$  and the non-negativity of the terms of  $\mathbf{L}$ . This represents in mathematical terms the vitality, also called productivity, of the economic system, i.e., the capacity of each productive sector to generate an output higher than what is used as an intermediate input by all sectors. Leontief's IO model expressed according to (1) is a demand driven model, as the final demand expresses the driving force of the economy. Generally, in a Leontief IO model the final demand volumes are identified exogenously, assuming that production levels adapt to the same final demand. As a result of the considered hypothesis, namely if the technical conditions of a vital economic system are considered stable (i.e., the matrix  $\mathbf{A}$  has values that may be considered as constants, the matrix  $(\mathbf{I} - \mathbf{A})$  is invertible and the Leontief inverse  $\mathbf{L}$  has non-negative values), Equation (1) can be used to predict the production  $\mathbf{q}^*$  of the economic system in a condition of equilibrium to satisfy an exogenous final demand  $\mathbf{f}^*$ , being  $\mathbf{q}^* = \mathbf{L} \cdot \mathbf{f}^*$ . This model is referred to as a Regional Impact Model (Schaffer, 1999), because it allows to quantify the impact on the value of economic production in the region, due to the change in final demand.

## 2.2. Extensions of the basic IO model

Starting from the single region basic model (Single Region IO - SRIO), the need to consider the geographical dimension (therefore, exchanges between regions) has led to multiregional IO models. Among them, we can mainly refer to the Inter-Regional IO - IRIO (Isard, 1951) or Multi-Regional IO - MRIO (Chenery, 1953) (Moses, 1955) models, based on different hypotheses for the derivation of the matrix of technical coefficients (direct knowledge in IRIO models by means of explicit multi-regional IO tables, or approximate estimates based on the IO tables for each region and trade flows between each pair of regions within the study area - through the so-called trade coefficients - in the MRIO models).

IO model extensions have been formulated considering elastic exchange coefficients (Min et al., 2001) (Timmermans, 2003), in order to investigate the dynamics of the interactions between transport and economic systems, an aspect not allowed by the assumption of coefficient constancy (Yu, 2018). They relate mainly MRIO models with exchange coefficients based on random utility models, that are called Random Utility-Based MRIO or RUBMRIO (De la Barra, 1989) (Jin et al., 2005) (Cascetta et al., 2013) (Bachmann et al., 2014). These models define elastic functions for the description of flows between regions allowing to estimate dynamic and sensitive trade coefficients to exogenous variations in transport systems (Yu, 2018) (Bachmann et al., 2014).

Further extensions of the MRIO models, and in particular of the RUBMRIO models, may concern the explicit representation of the feedback between the economic system and transport systems, modeling the elasticities with respect to the generalized costs of transport (Cascetta et al., 2013). Other modeling solutions have been introduced considering time-variability, e.g., dynamic IO models to simulate the variation in the availability of production factors resulting from past investments (Leontief, 1966) (Miller & Blair, 2009) (D'Antonio, 1980) or effects related to technological changes with future projection of technical coefficients (Miller & Blair, 2009) (Bachmann et al., 2014).

Drawing on the different specifications above, a Decision Support System (DSS) (Yu, 2018) (Cascetta et al., 2013) has been proposed for usage in transport field in comprehensive vision, based on two essential components: on the one hand, a RUBMRIO model; on the other hand, a sequence of models for the evaluation of transport costs and modal choices (Cascetta, 2009). The implementation of such structure is able to integrate a MRIO with elastic coefficients model with procedures for evaluating the generalized costs of transport and also allows to represent the feedback between the economic system and the transport system. However, this complexity - dictated by the complex articulation of modelling structures and the availability of adequate data - can generate real obstacles to the use of IO models on the part of those stakeholders involved in concrete decision for transport infrastructures (Mauro & Pompigna, 2020).

### 2.3. An Input Output model for the traffic macro-analysis on a freight corridor

Alises & Vassallo (2016) introduce a macro-level IO approach for freight demand analysis, which directly relates the quantities of goods transported by a given transport system to the functioning of the economic system, representing the latter through an SRIO type model. From the aforementioned point of view, we can consider a certain geographical region and introduce a measure of intensity for freight transport, represented by the so-called Freight Transport Intensity ratio (FTI) (Alises & Vassallo, 2016) (Brunel, 2005) (McKinnon, 2007) (Kveiborg & Fosgerau, 2007). Generally, the FTI can be expressed as the number of transport units per unit of GDP (Brunel, 2005) or per unit of productive output (Alises & Vassallo, 2016) (Åhman, 2004) by the economic system. The FTI can be disaggregated by economic sector, using the structure by productive branches of the IO approach. Furthermore, it can be expressed with detail on each component of the whole transport system (e.g., road, railway, multimodal, etc.). FTI values can be represented, for example, by the total distances travelled per unit of GDP or production (e.g., vehicle\*km/euro for road transport, tons\*km/euro for rail transport, etc.) or by the number of traffic units per unit of GDP or production (e.g., number of trains/euro in rail transport or TEU/euro in combined transport, etc.).

If we operate considering a whole freight transport system - which may coincides with an infrastructure corridor for freight traffic - and the  $N$  sectors that characterize the economic system of references, through the vector of production by sector  $\mathbf{q}$  it is possible to identify the vector  $\mathbf{FTI}$  of the sectorial values of the Freight Transport Intensity ratio at the corridor according to its definition:

$$\mathbf{FTI} = \text{diag}(\mathbf{q}^{-1})\mathbf{T} \quad (2)$$

where  $\mathbf{T}$  is a vector whose components express the freight transport demand by sector on the corridor (e.g., vehicles\*km, tons of goods, etc.). Considering the fundamental Leontief relation  $\mathbf{q} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{f}$ , we can write (Alises & Vassallo, 2016):

$$\mathbf{T} = \text{diag}((\mathbf{I} - \mathbf{A})^{-1}\mathbf{f})\mathbf{FTI} = \text{diag}(\mathbf{L}\mathbf{f})\mathbf{FTI} \quad (3)$$

Therefore, the vector  $\mathbf{FTI}$  makes it possible to integrate the representation of freight traffic flows along the corridor in the general formulation of the IO model. If the vector  $\mathbf{FTI}$  and the Leontief inverse matrix  $\mathbf{L}$  are available for a given region in a given reference period, it is possible to evaluate the effects of a variation of the final demand  $\mathbf{f}$  on the corridor transport demand  $\mathbf{T}$  by means of Equation (3) The components of the vector  $\mathbf{FTI}$  by sector may be known directly, deriving from specific surveys, or estimated through a specific chain of multiplicative factors (Alises & Vassallo, 2016).

The availability of annual IO tables, and of the related Leontief inverse matrices, within a certain time interval makes it possible to study the time evolution of the influences exerted by the economic system on the transported goods through Equation (3) at annual intervals. For the generic annual interval  $t$ , the model can be written as follows:

$$\mathbf{T}_t = \text{diag}(\mathbf{q}_t)\mathbf{FTI}_t = \text{diag}(\mathbf{L}_t\mathbf{f}_t)\mathbf{FTI}_t \quad (4)$$

In this sense, for the annual interval  $t$ , all the effects on the freight corridor (in the strict sense on the transported goods quantities expressed by  $\mathbf{T}_t$ ) are driven by the final demand  $\mathbf{f}_t$  through the total production in the economic system  $\mathbf{q}_t$  and taking into account the inverse Leontief matrix  $\mathbf{L}_t$ . As expressed by Equation (4), the model maintains the disaggregation of freight transport demand  $\mathbf{T}_t$  by the components  $T_i$  for each sector  $i$  between 1 to  $N$ . By expressing the aggregate goods demand with  $T_t$  (i.e.,  $T_t = \sum T_t(i)$ ) and indicating with  $\mathbf{FTI}_t'$  the row vector corresponding to  $\mathbf{FTI}_t$ , the model can be written in the following aggregate expression:

$$\mathbf{T}_t = \mathbf{FTI}_t'(\mathbf{L}_t\mathbf{f}_t) \quad (5)$$

Aggregate expressions of the type of Equation (5) are used by (Alises & Vassallo, 2016) (Alises et al., 2014) (Alises & Vassallo, 2015) considering the total of goods handled at a national level to analyze the different coupling/decoupling situations among the various European countries.

The model, broken down by sector according to Equation (4) or aggregated according to Equation (5), can be used to produce forecasts on future horizons, in terms of expected freight traffic on the cor-

ridor against a given final demand level  $f_t$ . Considering Equation (4) - the same considerations apply for Equation (5) - the model equation can be understood as a relation between the dependent variable  $T_t$  and the independent variable  $f_t$  with parameters  $L_t$  and  $FTI_t$ . In order to apply Equation (4), the parameters must be estimated. To do this we can assume a year  $t_0$  as reference, for which both the inverse Leontief matrix  $L_{t_0}$  and the sectoral transport intensities vector  $FTI_{t_0}$  are known. The demand for freight transport  $T_t$ , in correspondence with an expected final demand equal to  $\bar{f}_t$ , can be estimated with the following equation:

$$\hat{T}_t = \text{diag}(L_{t_0}\bar{f}_t)FTI_{t_0} \quad (6)$$

The model (6) keeps an essential characteristic of the Leontief model, namely that of being demand driven. Indeed, the final exogenous demand appears as the driving force of the economy. This characteristic actually distinguishes the model proposed in this paper from the versions used in (Alises & Vassallo, 2016) (Alises et al., 2014) (Alises & Vassallo, 2015), in which the final demand is replaced by the sum of GDP and imports. If the latter position is applicable in an aggregate manner considering all the sectors (due to the intrinsic equilibrium of the rows and columns of the IO tables), the same thing does not happen in the most general case if the sectoral disaggregation is maintained. The expression of the IO model through GDP and imports with sectoral disaggregation can take place only in the form of the Gosh supply-driven model (Ghosh, 1958), which cannot be solved simultaneously with the corresponding Leontief demand-driven model (Aroche Reyes & Marquez Mendoza, 2014). For a discussion of Gosh supply-driven model and its problems, also in relation to classic Leontief demand-driven approach, refer to (Miller & Blair, 2009) (Ghosh, 1964) (Oosterhaven, 1988) (Gruver, 1989) (De Mesnard, 2009).

The working hypothesis of using figures with respect to the reference year  $t_0$  is sustainable within the period between reference and forecasting horizons if the constancy of  $L$  and  $FTI$  can be reasonably hypothesized. In general, an IO model can be used for evaluating changes in sectoral production if the technical coefficients of the matrix  $A$  (and then the Leontief coefficients of the matrix  $L$ ) can be considered constant over time (Miller & Blair, 2009). This

essential feature of Leontief model, which does not consider a technological change within the productive system - characterized by cross-sector homogeneity - also expresses the hypothesis of no scale or learning economies, and the non-substitutability between production factors within a given production process. It is clear that this constraint can be considered acceptable only for narrowed forecasting horizons (i.e., a few years).

With the increasing of the gap between reference and forecast intervals, changes in technological systems and specialization structures for production could change in a non-negligible way, making poorly realistic the invariance of  $A$  (and therefore of  $L$ ) as anchored to  $A_{t_0}$  (and therefore to  $L_{t_0}$ ). In this case we can act against time-variability of  $A$  and  $L$  with specific models that allow their projection on future horizons (i.e., between  $t_0$  and  $t$ ) (Miller & Blair, 2009) (Bachmann et al., 2014) based on: trend models; marginal coefficients; best practice approach, considering the current most advanced manufacturer as future standard in the sector; bi-proportional iterative fitting (Deming & Stephan, 1940) known as RAS method (Bacharach, 1970) for balancing IO tables.

Similar considerations can also be made for  $FTI$  invariance and the related possibility of assuming the reference year value  $FTI_{t_0}$  according to different time horizons. Also in this case, as  $FTI$  by sector appears to be sensitive to time changes related to the technological, organizational, productive, logistic and territorial processes, it is possible to act against the temporal variability of the  $FTI$  components using some specific models that, starting from the values estimated at the reference period  $FTI_{t_0}$ , allow for their projection on future horizons (i.e., between  $t_0$  and  $t$ ). For this purpose, simple trend models or even more sophisticated approaches with multivariate models calibrated on historical data can be used. As effective application of the above, in the following section we propose an aggregate IO analysis of the annual freight transport demand on an Alpine corridor. The model represented by Equation (5) is applied to the analysis of the trend of tonnages of goods annually transited at the Brenner pass, on the border between Italy and Austria, considering the whole Italian economic system as a reference for the underlying IO model.

### 3. Model specification

#### 3.1. The Brenner Pass

The Brenner corridor is the central portion of the Munich-Verona corridor, a backbone of the European infrastructure network and part of the Scandinavia-Mediterranean Core Corridor of the TEN-T network for north-south connections. The Brenner pass is namely the part of the corridor crossing borders between Italy and Austria, connecting the two transalpine portions of the Euregio Tirolo-Alto Adige-Trentino. From the infrastructural point of view, the Brenner corridor is characterized by the presence of: an ordinary road infrastructure consisting of the Brennerstrasse B 182 (Austrian side) - SS12 del Brennero (Italian side); a motorway infrastructure consisting of A13 Brenner Autobahn (Austrian side) - A22 Autostrada del Brennero (Italian side); a railway infrastructure consisting of the Brennerbahn Innsbruck / Brenner (Austrian side) - Ferrovia Brennero / Verona (Italian side).

The Brenner Pass is currently the most intensely trafficked pass in the entire Italian Alpine region. Taking into consideration the Italian Alpine borders, in 2017 the share of goods that crossed the Brenner in both directions represents 25% of the total volume transited, about 10.5% of the whole Italian trade (Cascetta, 2019). During 2018, freight traffic at the Brenner pass was just below 50 million tons, with a modal split clearly tending towards the road (72% of goods transported) (iMONITRAF!, 2018).

Over the years, the modal shift has become a central topic in regional, national and European policies, that have identified push and pull measures aimed at transferring significant amounts of freight traffic from road to rail (Nocera et al., 2018). From this point of view, in 2018 the Euregio Tirolo-Alto Adige-Trentino approved its strategy, highlighting the objectives for a shared transport policy along the Brenner axis and targeting a balance of transport modes in 2027 and a reversal up to 2035 (GECT, 2018).

However, the current structure of the Brenner railway leaves little room for manoeuvre. Among the interventions that will promote the attractiveness of rail transport and push towards a modal transfer from motorway, the construction of the Brenner Base Tunnel - Brenner Basistunnel (BBT) stands out greatly. The intervention, currently in progress, with the strengthening of the Verona - Fortezza access

lines from the south, is an integral part of the infrastructural interventions on the Scandinavia-Mediterranean Core Corridor of the European TEN-T network.

In this context, the analysis and forecasting of goods traffic on the Brenner Alpine corridor is of fundamental importance for the planning and management of the concerned infrastructures. Starting from the preliminary studies for the construction of the BBT (GEIE BBT, 2002) (ProgTrans), the definition of forecasts for the corridor freight demand and its modal distribution has been subject to constant interest by some stakeholders involved in planning processes over time (Alpine Convention, 2007) (ScanMed RFC, 2014). 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: (Mauro & Cattani, 2018) with logistic curves for medium and long-term forecasts, resulting from transport policy scenarios and operational measures; (Mauro & Pompigna, 2019) with econometric models and techniques for time series analysis with dynamic components and capacity constraints, with respect to different scenarios of macroeconomic and infrastructural evolution.

#### 3.2. The basic data for the freight corridor model at the Brenner pass

The model outlined in section 2.3 is applicable to the Brenner pass considering the annual freight volumes (road + rail) and assuming the entire Italian national territory as the reference region for the basic SRIO model. For the application of the model as in Equation (4), in this study we have considered the Input Output tables for Italy in the WIOD 2016 database (Timmer et al., 2015). The Italian IO tables were extracted from the general database, which covers 43 countries, according to the ISIC Rev. 4 56-sector classification both in current year prices and previous year price, in millions of US dollars for each year between 2000 and 2014. The original IO tables were recalculated in millions of euro at constant prices at base year 2000. To facilitate model processing and analysis, the 56 ISIC Rev. 4 sectors were aggregated 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 the IO tables described above, for each year  $t$  between 2000 and 2014 the matrices of the technical coefficients  $A_t$  and the inverse matrices of Leontief  $L_t = (I - A_t)^{-1}$  have been analyzed to highlight their temporal trends and to test their

stability. Figure 2 shows the graphs of the elements of  $A_{2000}$  (Fig. 2a) and  $A_{2014}$  (Fig. 2b), respectively in the first and in the last year of the available WIOD time series, while Table 1 shows the percentage differences between the beginning (2000) and the end (2014) of the period for each element of  $A$ .

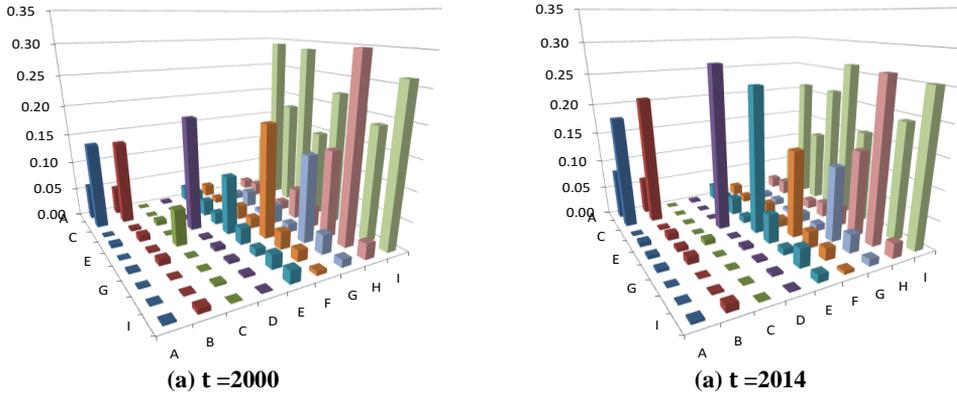


Fig. 2. Technical coefficients for 2000 (a) and 2014 (b) (based on WIOD 2016 data at constant prices 2000)

Table 1. Technical coefficients variations - Percent differences for years 2000 and 2014

| Percent differences $A_{2000} - A_{2014}$  |   | A    | B    | C    | D    | E     | F    | G    | H    | I    |
|--|---|------|------|------|------|-------|------|------|------|------|
| Agriculture, hunting, fishing and forestry | A | 40%  | 28%  | 70%  | 50%  | 2386% | 66%  | 53%  | 18%  | 42%  |
| Food, drink and tobacco                    | B | 30%  | 51%  | -33% | 4%   | 103%  | 25%  | -24% | 57%  | 40%  |
| Mining and construction                    | C | -37% | 22%  | -86% | 28%  | -86%  | -27% | 18%  | -68% | 17%  |
| Textile                                    | D | 18%  | -32% | -52% | 42%  | -44%  | -12% | -27% | 6%   | 20%  |
| Energy, fuel and energy products, waste    | E | 4%   | -29% | 12%  | -41% | 142%  | 73%  | -13% | 36%  | -39% |
| Chemical products                          | F | -15% | 20%  | 4%   | 12%  | -25%  | -23% | -8%  | 6%   | -24% |
| Transport machinery and equipment          | G | 4%   | -28% | -64% | -7%  | -52%  | -19% | -14% | -5%  | -13% |
| Manufactured products                      | H | 18%  | 12%  | -55% | -1%  | -52%  | -3%  | -2%  | -11% | -5%  |
| Services                                   | I | -31% | -27% | -31% | -26% | 77%   | -29% | -9%  | 2%   | -3%  |

Source: elaboration on WIOD 2016 data at constant prices 2000

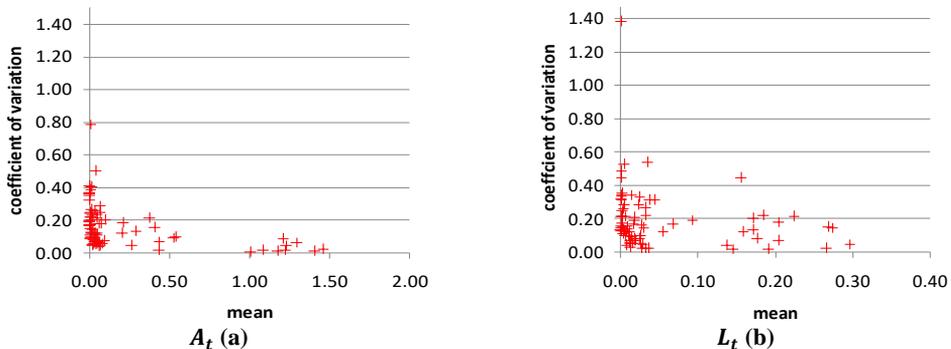


Fig. 3. Average value and coefficient of variation in the period 2000 - 2014 for the elements of  $A_t$  and  $L_t$  (elaboration on WIOD 2016 data at constant prices 2000)

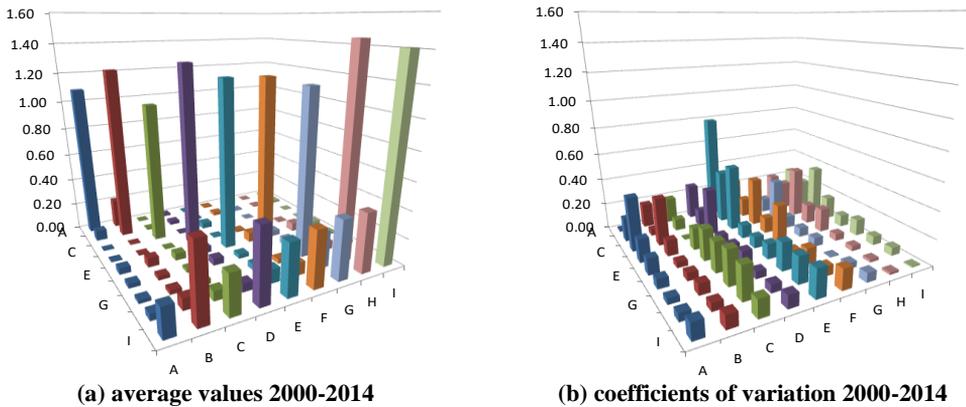


Fig. 4. Average values and coefficients of variation of Leontief multipliers for the 9-sector IO tables between 2000 and 2014 (elaboration on WIOD 2016 data at constant prices 2000)

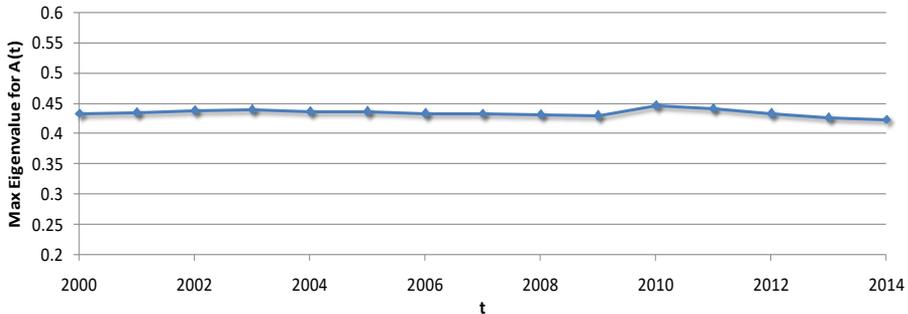


Fig. 5. Maximum eigenvalue for  $A_t$  between 2000 and 2014 (elaboration on WIOD 2016 data at constant prices 2000)

Figure 3 shows the relationship between the 15-year average value for each technical coefficient  $a_{ij,t}$  (Fig. 3a) and the Leontief multipliers  $l_{ij,t}$  (Fig. 3b) over the whole period 2000 - 2014 and the relative coefficient of variation. The graphs in Figure 3 show how the largest variations emerge for the smaller coefficients and multipliers. For high-value coefficients in  $A_t$  ( $> 20\%$ ) and multipliers in  $L_t$  ( $> 1$ ) the coefficients of variation over the entire period are respectively  $< 0.2$  and  $< 0.1$ . This indicates a standard deviation of an order of magnitude lower than the average value.

Considering the Leontief multipliers for the 9 sectors, Figure 4 shows the average values (Fig. 4a) and the variation coefficients (Fig. 4b) in the 15-year period.

The maximum eigenvalue of the technical coefficients matrix in Figure 5 shows a substantially stable

situation over the time. Also it provides a measure of the intermediate input share with respect to the total production to indicate the efficiency of the economic system (Duchin & Steenge, 2007). This corresponds to a substantial technological stability, with non relevant changes in the coefficients. It emerges, however, a slightly decreasing trend, which shows a tendency to greater efficiency of the economic system over the years, excluding the singular increasing value for 2010 as a probable effect of the economic crisis.

For the freight demand characterization, we considered the total tonnage that crossed the Brenner pass in the interval 2000-2017 as reported in (iMONI-TRAF!, 2018) and (DG Move - Swisse OFT, 2019). Table 2 and Figure 6 show the time series of the tons of goods transported annually, as a sum between road and rail values.

Table 2. Time series of total tonnages between 2000 and 2017

| 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                                    |
| 2015 | 43.7                                    |
| 2016 | 46.9                                    |
| 2017 | 49.4                                    |

Source: (iMONITRAF!, 2018) (DG Move - Swisse OFT, 2019)

The annual level of tons for year  $t$  represent the total  $T_t$  of the sectoral components of the vector  $T_t$ . As expressed by Equation (4), total goods  $T_t$  must be recorded separately, considering the same sectoral components that characterize  $A_t$  and  $L_t$  matrices (see Equations (4)). For this purpose, the annual tons of goods exchanged in international trade (import + export) between Italy and the countries of the corridor were analyzed using national official databases (Istat Coeweb, 2019). As shown in (European Commission, 2018), the following countries were considered for the analysis: Belgium; Luxembourg; Norway; Netherlands; Sweden; Finland; Austria; Germany; UK; Denmark.

Time series of tonnages of goods exchanged, as extracted from the overall database with classification NST2007 (European Commission, 2007), have been reclassified according to the 9-sector structure identified above, for the complete characterization of each vector  $T_t$  between 2000 and 2017 (see Figure 7).

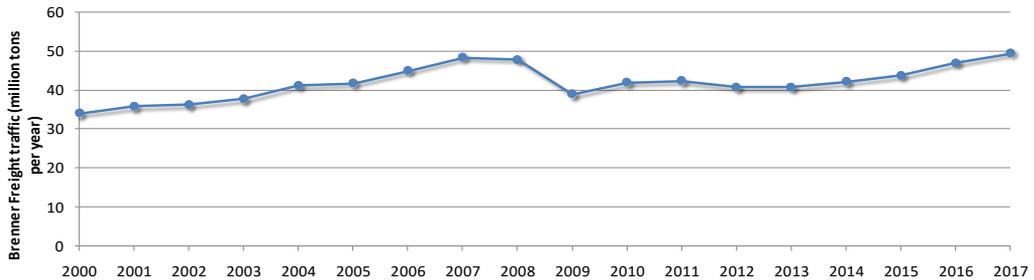


Fig. 6. Time series of total tonnages between 2000 and 2017 (iMONITRAF!, 2018) (DG Move - Swisse OFT, 2019)

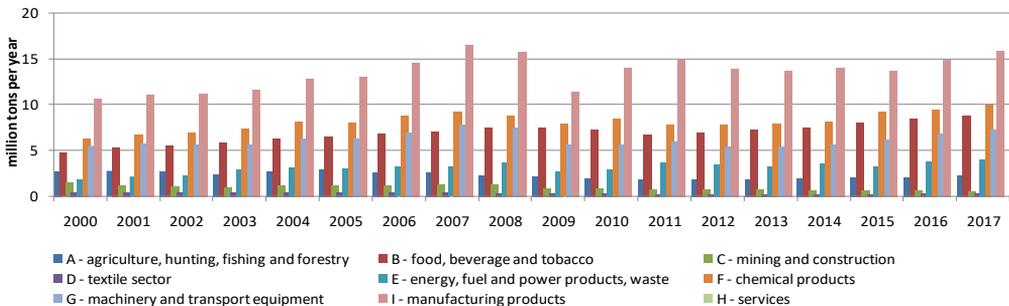


Fig. 7. Sectoral distribution of annual tons transported at the Brenner pass between 2000 and 2017 - estimates on (Istat Coeweb, 2019) (iMONITRAF!, 2018) (DG Move - Swisse OFT, 2019)

Based on the vector  $T_t$  of the annual tons of goods transported at the Brenner by sector and the vector  $q_t$  of the national production by sector derived from the reclassified IO tables already mentioned, for each year  $t$  between 2000 and 2014 the vectors of the sectoral traffic intensities at the pass were obtained, i.e.,  $FTI_t = diag(q_t^{-1})T_t$ . Figures 8 and 9 represent, respectively as absolute terms (annual tons transported to the Brenner per million euro of national production) and as index

numbers with base year 2000, the trends of the components of  $FTI_t$ . The index numbers (base year 2000) show essentially a growth over the 15 years for values relating to: food, beverages and tobacco; manufacturing 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. Figure 10 shows the trend of the coefficient of variation for the years 2000-2014 of the sectoral  $FTI_t$ s at the Brenner pass.

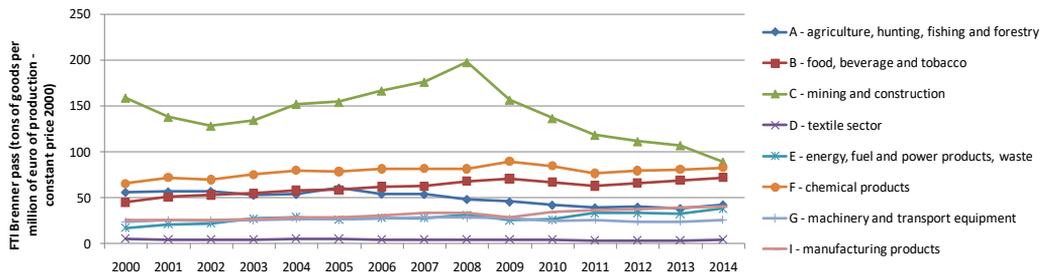


Fig. 8. Time evolution for FTI by sector at Brenner pass between 2000 and 2014 (tons of goods per million of euro of production - constant price 2000)

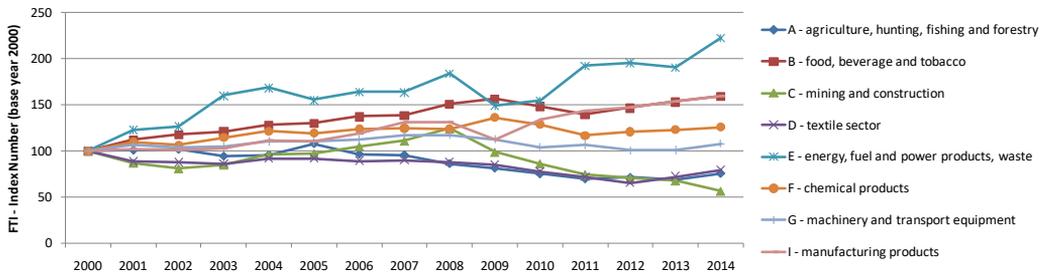


Fig. 9. Time evolution for FTI Index number by sector (base year 2000) at Brenner pass between 2000 and 2014

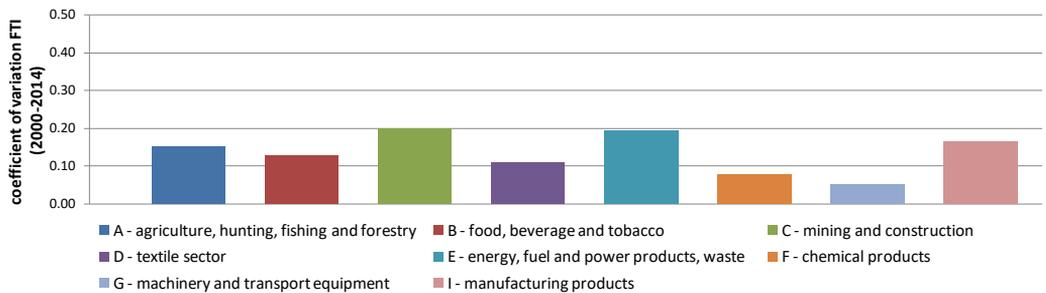


Fig. 10. Coefficient of variation for FTI by sector at Brenner pass between 2000 and 2014

### 3.3. Year-on-year predictability for total production and corridor freight traffic

Based on the data available for each year  $t$  between 2000 and 2014, it is possible to verify the on-sample forecasting capacity of the IO model, regarding both the production and the tons of goods transported.

The on-sample forecast relates to  $\mathbf{q}_{t+1}$  and  $\mathbf{T}_{t+1}$  for year  $t + 1$  based on the exogenously known final demand  $\bar{\mathbf{f}}_{t+1}$  and the values  $\mathbf{L}_t$  and  $\mathbf{FTI}_t$  for the previous year  $t$ . In formulas, the forecast model is expressed through the following equations:

$$\hat{\mathbf{q}}_{t+1} = \mathbf{L}_t \bar{\mathbf{f}}_{t+1} \quad (7)$$

$$\hat{\mathbf{T}}_{t+1} = \text{diag}(\hat{\mathbf{q}}_{t+1}) \mathbf{FTI}_t \quad (8)$$

In analyzing the predictive capacity year-on-year, for each time interval  $t + 1$  with varying  $t$  a comparison is made between the known value of production  $\mathbf{q}_{t+1}$  and the estimated value  $\hat{\mathbf{q}}_{t+1}$  (Equation (7)) and between the known value of the tons transported  $\mathbf{T}_{t+1}$  and the estimated one  $\hat{\mathbf{T}}_{t+1}$  (Equation (8)). The comparison is made by calculating the MAPE (Mean Absolute Percentage Error) and the RMSE (Relative Mean Square Error). A further

comparison can be made in overall terms, calculating the percentage deviation between known and estimated values as total on all 9 economic sectors. Table 3 shows the results gained for each forecast year  $t + 1$  between 2001 and 2014. The results for the production show peaks of the MAPE and the RSME which remain respectively below 10% and 30%, reached in the years 2009 and 2010 when the occurrence of the crisis generated peculiarities of the economic system difficult to foresee considering the values of the previous year for Leontief multipliers. As for the prediction of the tons of goods transported, MAPE and RMSE are significantly higher. Since the value estimated with the Equation (7) for the production is used in order to obtain the estimate of the tons of goods transported by the Equation (8), naturally in the second estimate the errors of the first are proposed again (the latter linked, as mentioned, to the hypothesis of constant multipliers compared to the previous year). We have to add also the effects deriving from having considered in Equation (7) the previous year values for sectoral  $\mathbf{FTI}$ s. As already discussed in section 3.2 and shown in Figures 8, 9 and 10, the components of  $\mathbf{FTI}$  can be characterized, in fact, by a non-negligible variability.

Table 3. Year-on-Year predictability for the IO corridor model (Equations (7) and (8))

| Year $t+1$ | National Production                            |      |                                | Tons of goods transported at Brenner Pass      |      |                                |
|------------|--|------|--------------------------------|--|------|--------------------------------|
|            | all the components of $\hat{\mathbf{q}}_{t+1}$ |      | Total $\hat{\mathbf{q}}_{t+1}$ | all the components of $\hat{\mathbf{T}}_{t+1}$ |      | Total $\hat{\mathbf{T}}_{t+1}$ |
|            | MAPE   | RMSE | %Dif                           | MAPE   | RMSE | %Dif                           |
| 2001       | 1%   | 4%   | -1%                            | 10%  | 28%  | -4%                            |
| 2002       | 1%   | 4%   | -1%                            | 3%   | 9%   | 0%                             |
| 2003       | 2%   | 5%   | 0%                             | 11%  | 32%  | -7%                            |
| 2004       | 2%   | 5%   | 1%                             | 5%   | 15%  | -6%                            |
| 2005       | 1%   | 4%   | 0%                             | 3%   | 9%   | 1%                             |
| 2006       | 2%   | 6%   | 1%                             | 5%   | 15%  | -3%                            |
| 2007       | 1%   | 3%   | 0%                             | 3%   | 7%   | -4%                            |
| 2008       | 2%   | 5%   | 0%                             | 5%   | 14%  | -1%                            |
| 2009       | 10%  | 30%  | 0%                             | 20%  | 55%  | 7%                             |
| 2010       | 10%  | 30%  | -1%                            | 10%  | 28%  | -7%                            |
| 2011       | 3%   | 8%   | 1%                             | 7%   | 20%  | 0%                             |
| 2012       | 2%   | 6%   | 1%                             | 5%   | 14%  | 0%                             |
| 2013       | 7%   | 22%  | 1%                             | 10%  | 30%  | 0%                             |
| 2014       | 3%   | 8%   | 1%                             | 6%   | 16%  | -4%                            |
| Average    | 3%   | 10%  | 0%                             | 7%   | 21%  | -2%                            |

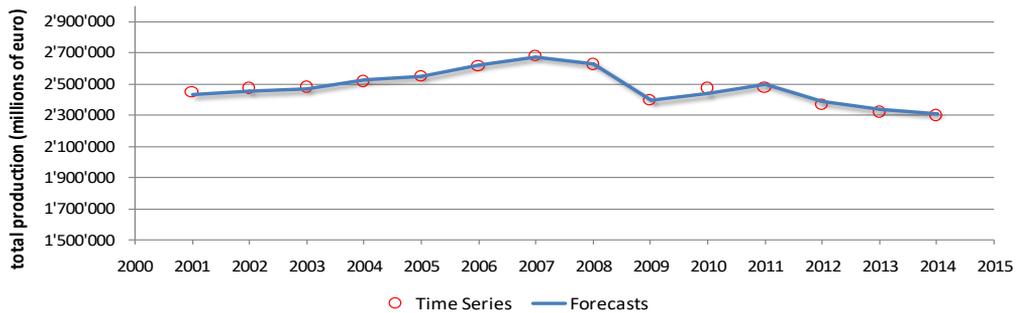


Fig. 11. Total national production - Time series and model (7) estimates

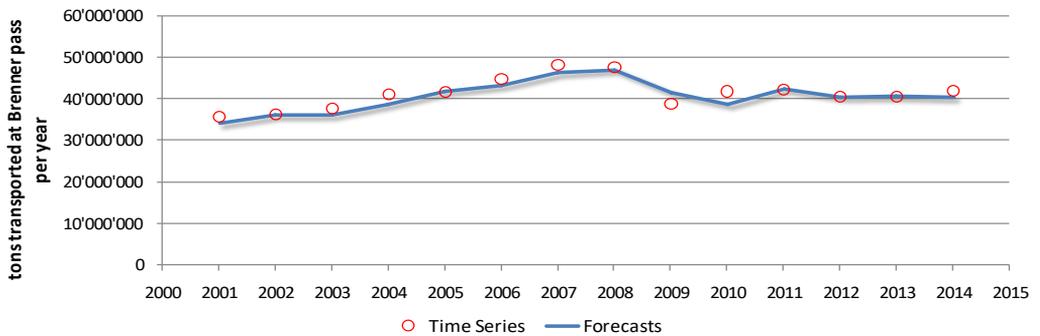


Fig. 12. Total tons of goods transported at the Brenner pass - Time series and model (8) estimates

The results seem clearly better if we consider the total production  $q_t = \sum q_t(i)$  and the total tons of goods transported  $T_t = \sum T_t(i)$ , with maximum deviations which do not exceed  $\pm 1\%$  for production and  $\pm 7\%$  for tons. Figures 11 and 12 show time series and forecast values year by year, respectively for the total production and the total tons transported.

### 3.4. Long-term predictability for total production and corridor freight traffic

Always using the data available from 2000 to 2014, it is possible to verify the forecasting capacity of the IO model, regarding both the production  $\hat{q}_{2014}$  and the tons of goods transported  $\hat{T}_{2014}$  for the year 2014 based on the values of  $L_t$  and  $FTI_t$  with varying  $t$  between 2000 and 2013. The forecasting model is expressed through the following equations:

$$\hat{q}_{2014|t} = L_t \bar{f}_{2014}, \quad \forall t = 2000, 2001, \dots, 2013 \quad (9)$$

$$\hat{T}_{2014|t} = \text{diag}(\hat{q}_{2014}) FTI_t, \quad \forall t = 2000, 2001, \dots, 2013 \quad (10)$$

where  $\bar{f}_{2014}$  is an exogenously known final demand. Also in this case a comparison can be made in terms of MAPE and RMSE between: the known value of production  $q_{2014}$  and the estimated value  $\hat{q}_{2014|t}$  for each  $t$  in the period 2000-2013 (Equation (9)); the known value of the tons of goods transported  $T_{2014}$  and the estimated value  $\hat{T}_{2014|t}$  for each  $t$  in the period 2000-2013 (Equation (10)).

Table 4 shows MAPE and RMSE values, while Figures 13 and 14 present percentage differences between time series and estimated values for total production and total freight traffic with varying  $t$ . Also in this case the sectoral production forecasts are better than those of the tons of goods transported. This difference can be linked to the lower variability of multipliers (in consideration of the amount of sectoral demand) compared to the variability of FTIs.

The MAPE and RMSE values for production assume a decreasing trend from 2000 to 2008, interrupted in 2009 by the variation in the sectoral distributions that occurred with the economic crisis. In the years 2009-2010 the two predictability measures assume the maximum deviations, respectively equal to 6% and 19%. The decreasing trend is much more evident for the tons transported. In this case the predictability measurements show their maximums in consideration of the widest gaps between the reference horizon and the forecasting one, assuming maximum values equal to 47% for MAPE and 133% for RMSE for the year 2001. Also in this case, the

trends with respect to the total production  $q_{2014|t}$  and of the tons transported  $T_{2014|t}$  are highlighted. Figures 13 and 14 show the trends, with variations in  $t$ , of the percentage deviation between the estimated and measured totals, respectively for production and for the tons transported. The graphs clearly show that the estimate becomes progressively more accurate when the time gap between the estimate horizon (2014) and the previous data used to make the forecasts ( $t = 2000, 2001, \dots, 2014$ ) is being reduced.

Table 4. Long-term predictability for the IO corridor model (Equations (10) and (11))

| Year $t$ | National production                      |      |      | Tons of goods transported at Brenner Pass |      |      |
|----------|--|------|------|---|------|------|
|          | all the components of $\hat{q}_{2014 t}$ |      |      | all the components of $\hat{T}_{2014 t}$  |      |      |
|          | MAPE                                     | RMSE | %Dif | MAPE                                      | RMSE | %Dif |
| 2000     | 5%                                       | 16%  | 2%   | 47%                                       | 133% | -23% |
| 2001     | 4%                                       | 13%  | 3%   | 36%                                       | 103% | -20% |
| 2002     | 4%                                       | 13%  | 4%   | 32%                                       | 90%  | -20% |
| 2003     | 3%                                       | 10%  | 4%   | 29%                                       | 83%  | -16% |
| 2004     | 3%                                       | 8%   | 3%   | 31%                                       | 89%  | -11% |
| 2005     | 2%                                       | 6%   | 3%   | 32%                                       | 91%  | -12% |
| 2006     | 1%                                       | 2%   | 3%   | 32%                                       | 89%  | -9%  |
| 2007     | 0%                                       | 1%   | 3%   | 32%                                       | 92%  | -5%  |
| 2008     | 0%                                       | 1%   | 2%   | 34%                                       | 96%  | -4%  |
| 2009     | -3%                                      | 8%   | 2%   | 19%                                       | 53%  | -10% |
| 2010     | 6%                                       | 18%  | 4%   | 19%                                       | 53%  | -3%  |
| 2011     | 6%                                       | 19%  | 3%   | 16%                                       | 46%  | -4%  |
| 2012     | 6%                                       | 19%  | 2%   | 15%                                       | 43%  | -4%  |
| 2013     | 0%                                       | 1%   | 1%   | 6%  | 16%  | -4%  |
| 2014     | 0%                                       | 0%   | 0%   | 0%  | 0%   | 0%   |
| Average  | 3%                                       | 9%   | 3%   | 25%                                       | 72%  | -10% |

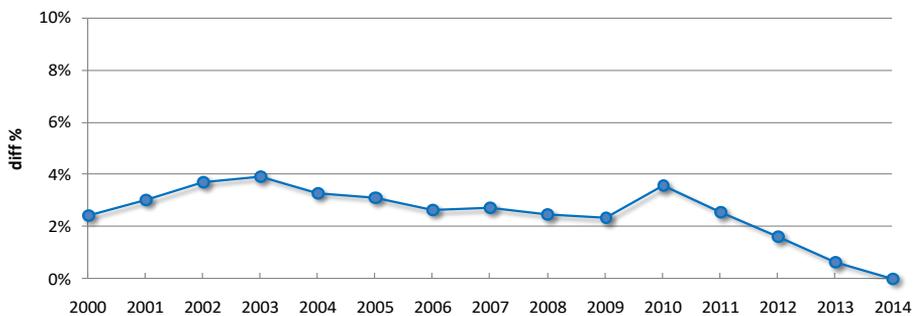


Fig. 13. % difference between model (10) estimates and actual value of total production during 2014

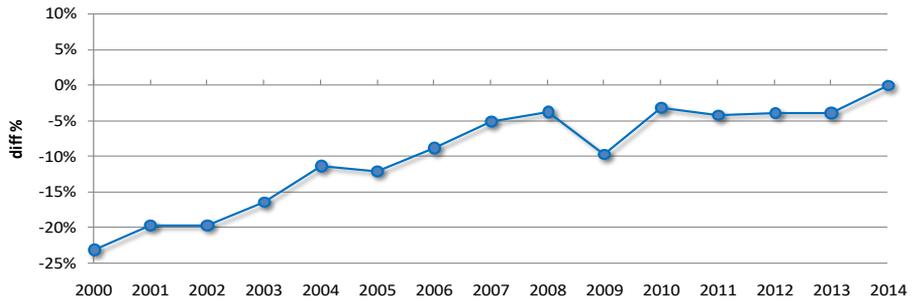


Fig. 14. % difference between model (11) estimates and actual value of total tons of goods transported at the Brenner pass during 2014

#### 4. Freight traffic forecasts

##### 4.1. Short-term forecasts validation

The IO model was used to make forecasts for the short period 2015-2017, i.e. "out of sample" forecasts since the IO matrices are not available for this three-year period. By first forecasts are carried out considering the following equations:

$$\hat{q}_t = L_{2014} \bar{f}_t, \quad \forall t = 2015, 2016, 2017 \quad (11)$$

$$\hat{T}_t = \text{diag}(\hat{q}_t) FTI_{2014}, \quad \forall t = 2015, 2016, 2017 \quad (12)$$

that is assuming constant values for  $L$  and  $FTI$  at 2014 values. The demand  $\bar{f}_t$  for each forecast year have been identified considering the variations of the total final demand  $f_t$ , in real terms compared to 2014, based on national data for the main aggregates of GDP (I.Stat, 2019). Table 5 shows the index numbers (base year 2014) to be applied to the total final demand  $f_{2014}$ , to obtain the total final demand  $\bar{f}_t$  in each year  $t$ . For the determination of the sectoral components of  $\bar{f}_t$ , the distribution of the total value compared to the production sectors in  $f_{2014}$  is assumed to be unchanged.

Since the total final production (2000 prices) (I.Stat, 2019) and the tons of goods transported at the Brenner (iMONITRAF!, 2018) (DG Move - Swisse OFT, 2019) are available for the three-year period, this information can be used for the validation of the results obtained by (11) for  $\hat{q}_t$  and by (12) for  $\hat{T}_t$ . Table 5 shows, as index numbers (base year 2014) the  $q_t$  values used for the validation of the results obtained with (11), while for the validation of the results obtained with (12) see the  $T_t$  values presented in Table 2 for the years in question.

Table 5. Real trend of total values of final demand and Italian production 2014-2017 - Index numbers for base year 2014 (based on national data)

| Aggregate value                                 | 2014   | 2015   | 2016   | 2017   | 2018   |
|---|--------|--------|--------|--------|--------|
| Index numbers of total final demand $\bar{f}_t$ | 100.00 | 100.87 | 101.99 | 103.69 | 104.65 |
| Index numbers of total production $q_t$         | 100.00 | 101.43 | 102.39 | 103.92 | 104.67 |

Considering that the sectoral disaggregation of production is not actually available, the following Equation (13) can be used instead of Equation (11), which allows to obtain the total value on all 9 sectors directly:

$$\hat{q}_t = i' L_{2014} \bar{f}_t, \quad \forall t = 2015, 2016, 2017 \quad (13)$$

where  $i'$  represents the unit row vector. Similarly, as regards the total of the tons transported on all the sectors  $T_t$ , this can be obtained by using the following Equation (14) (see Equation (5)):

$$\hat{T}_t = FTI'_{2014} L_{2014} \bar{f}_t, \quad \forall t = 2015, 2016, 2017 \quad (14)$$

Table 6 shows the percentage differences between the estimated value with Equations (13) and (14) and the actual value in the three years. The estimate of the total production  $q_t$  is characterized by extremely limited deviations, which do not exceed 1%. The same thing does not happen for the tons transported  $T_t$ , with progressively increasing deviations between 3% to 2015 and 12% to 2017.

About that, we have to notice that, since the forecasts were obtained by considering constant Leontief and *FTI* multipliers referring to 2014, the validity of the same forecasts may be conditioned by their variability, and in particular for *FTIs*. Therefore, a further estimate hypothesis has been made considering for each year 2015, 2016 and 2017 a forecast value for each sectoral *FTI*. For each year  $t = 2015, 2016, 2017$ , a forecast vector  $\widehat{FTI}_t$  can be assumed, instead of the constant vector  $\widehat{FTI}_{2014}$ , considering for each sector component the time regression of values for years 2012-2014. In these three years, as shown in Figures 8 and 9, there is a homogeneous trend in most of the sectoral components. In this case, the forecasts of the tons of goods are obtained considering the following equations:

$$\widehat{T}_t = \widehat{FTI}'_t L_{2014} \bar{f}_t, \quad \forall t = 2015, 2016, 2017 \quad (15)$$

$$\widehat{FTI}_{i,t} = \alpha_i + \beta_i t, \quad \forall t = 2015, 2016, 2017; \forall i \quad (16)$$

with  $\alpha_i$  and  $\beta_i$  the least squares regression coefficients estimated over the years between 2012 and

2014. The estimates in Table 6 obtained considering the regression model (16) appear significantly improved, with deviations that do not exceed 3%. Figure 15 shows the comparison between the values of the total tons transported according to the time series and the estimates obtained considering for the years 2001 - 2014 the aggregate values of model (9) and for the years 2015-2017 model (15) and (16) values.

**4.2. Freight traffic forecasts for long-term scenarios**

The model represented by Equation (13) for total production:

$$\hat{q}_t = i' L_{2014} \bar{f}_t, \quad \forall t \quad (13)$$

and Equations (15) and (16) for tons of goods:

$$\widehat{T}_t = \widehat{FTI}'_t L_{2014} \bar{f}_t, \quad \forall t \quad (15)$$

$$\widehat{FTI}_{i,t} = \alpha_i + \beta_i t, \quad \forall t; \forall i \quad (16)$$

Table 6. Short term predictability measures; estimate of 2015-2017 values based on 2014 reference year

| Year $t$ | Total tons of goods transported $\widehat{T}_t$ |   |               |
|----------|---|---|---------------|
|          | Total production<br>$\widehat{Q}_t$<br>%Dif     | FTI regression forecast model<br>(calibrated over 2012-2014 period) |               |
|          |   | FTI constant values 2014<br>Total<br>%Dif                           | Total<br>%Dif |
| 2015     | -0.6%   | -2.8%   | 0.1%          |
| 2016     | -0.4%   | -8.4%   | -2.6%         |
| 2017     | -0.2%   | -11.6%  | -3.0%         |
| Average  | -0.4%   | -7.6%   | -1.9%         |

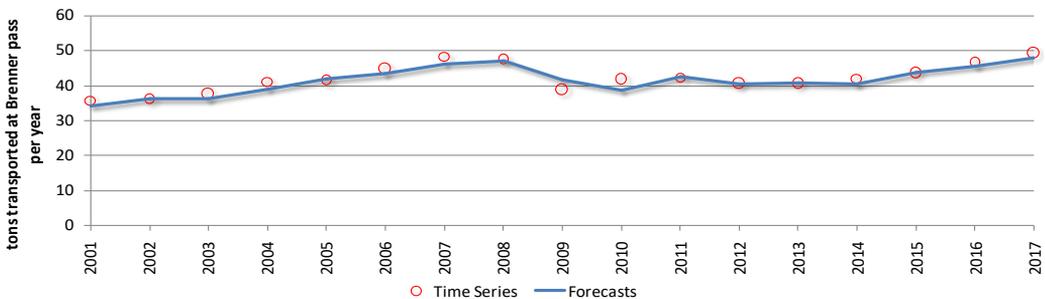


Fig.15. Total tons of goods transported at the Brenner pass – Time series and estimated values with model (9) between 2001 and 2014 and with model (16) (17) between 2015 and 2017

can be used to make forecasts for the medium and long term. The time horizon considered here is placed at 2027, the year in which it is possible to assume the completion of the New Brenner Base Tunnel (BBT) (Mauro & Cattani, 2018) (Mauro & Pompigna, 2019).

As Equations (13) and (15) show, within the forecast period we consider a constancy of the multipliers, represented for each year of forecast by  $L_{2014}$  matrix, while for the traffic intensities at the Brenner we use the time trend model with coefficient that are calibrated over the last three years of available data. Using Equation (16) a forecast is made for the evolution of FTIs, according to the linear trend model (with coefficients calibrated over the period 2012-2014) up to 2020. Beyond 2020, an invariance of the values is assumed up to 2027. Figure 16 shows the trend obtained for the sectoral components of the vector  $\overline{FTI}_t$ . The trends show an asymptotic stabilization for all sectors, with the exception of the mining and construction sectors where the sharp decline over the years is interrupted in 2020 with the assumption of consistency mentioned above.

The hypotheses for the total final demand  $f_t$  for the period 2020 - 2027 are reported in Table 7 as index

numbers with base year 2014. These values are obtained by applying the estimated time trend between 2014 and 2018 (Istat Coeweb, 2019) (I.Stat, 2019). The exogenous growth factors for  $f_t$  identified in Table 7 apply to the total  $f_{2014}$  to obtain the total values  $\overline{f}_t$  for in each of the forecast years. For each of the years  $t = 2018, \dots, 2027$  a variation in the final demand compared to the 2014 reference can be identified, i.e.,  $\Delta \overline{f}_t$ . The demand variation  $\Delta \overline{f}_t$  is then distributed over the 9 sectors in the analysis period based on three different scenarios, namely: as-is; industrialization; tertiarisation (cf. materialization-dematerialization for GDP growth in Alises & Vassallo (2016)).

The as-is scenario considers that the increase in final demand  $\Delta \overline{f}_t$  is distributed over the 9 sectors of the economy as the reference year 2014. The industrialization and tertiarisation scenarios consider the same increase in each year  $t = 2018, 2019, \dots, 2027$  divided respectively: for the first, only on the sectors with a high impact on goods (i.e., sectors A to H, excluding the services sector I) according to the relative percentages recorded in 2014; for the second, completely attributed to the non-freight-oriented sector (i.e., services sector I, excluding sectors A to H).

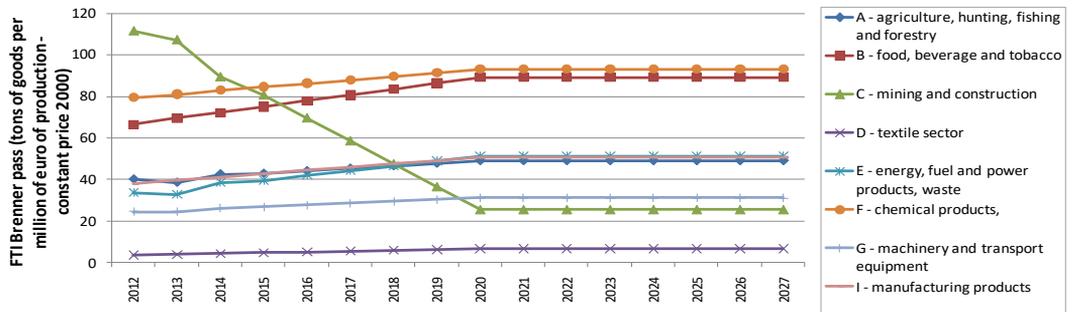


Fig. 16. Expected trend of the FTI at the Brenner pass (annual tons transported for million euro of sectoral production at constant prices 2000) from 2012 to 2027

Table 7. Expected trend for  $f_t$  for the period 2018-2027 - index numbers (base year 2014)

| Aggregate value                                      | 2018(*) | 2019   | 2020   | 2021   | 2022   | 2023   | 2024   | 2025   | 2026   | 2027   |
|--|---------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Index numbers of total final demand $\overline{f}_t$ | 104.6   | 103.45 | 104.66 | 105.87 | 107.09 | 108.30 | 109.51 | 110.72 | 111.93 | 113.15 |

source: 2018 value from calculations on (I.Stat, 2019) data; 2019 - 2027 values by linear regression forecasts on 2014-2018 national data (I.Stat, 2019)

Figure 17 shows the overall trend of the total national production value  $q_t$  (at constant prices referred to the base year 2000) in the period between 2000 and 2027. Specifically, Figure 17 shows: for the period 2000-2018, the time series values; for the period 2019-2027 the forecast values  $\hat{q}_t$  obtained with Equation (14) according to the assumptions underlying the three scenarios. In the comparison between these three scenarios, given the same exogenous final demand (see Table 7), it is clear how the production for each year is different in each scenario, due to the different relations that arise in the economic system in terms of intermediate exchanges between sectors. The industrialization scenario shows the highest production values, as it is able to stimulate intermediate trade more intensively within the economic system. The exact opposite is the case for the tertiarisation scenario with final demand increases limited to a single sector. The as-is scenario is in an intermediate position, with a more balanced

distribution of final demand increases within the 9 economic sectors.

Table 8 and Figure 18 show the forecast values  $\hat{T}_t$  for the three scenarios. In line with what results for the total production, the as-is scenario holds an intermediate position with respect to the industrialization scenario, which has higher values, and the tertiarisation scenario, which remains constantly lower. In 2027, i.e., the year of completion of the BBT works, the expected freight movement at the pass in the as-is scenario amounts to 57.11 million tons per year, an extremely close value to the forecasts with constant infrastructure in (Mauro & Pompigna, 2019). The estimated value shows a difference of 1.3 million tons/year compared to the capacity of the corridor, estimable in 58.4 million tons per year (Mauro & Pompigna, 2019) and therefore with a saturation level of 98%.

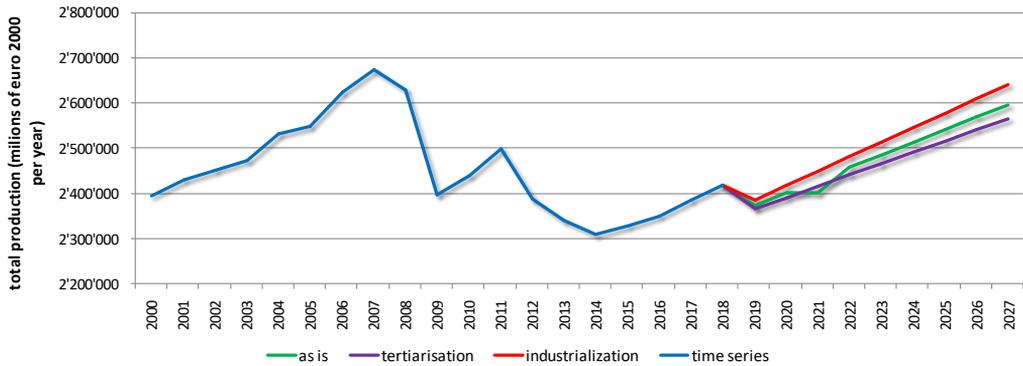


Fig. 17. Total national production (millions of euro at constant prices base year 2000) - time series for 2000-2018 (elaboration on (I.Stat, 2019) and WIOD 2016 data source) - forecast values for 2019 - 2027

Table 8. Annual tons of goods transported at the Brenner pass in the three forecast scenarios

| Year | tertiarisation | Scenarios as-is | industrialization |
|------|----------------|-----------------|-------------------|
| 2018 | 48.124         | 49.836          | 52.311            |
| 2019 | 49.432         | 50.741          | 52.633            |
| 2020 | 51.008         | 52.828          | 55.456            |
| 2021 | 51.148         | 52.842          | 56.751            |
| 2022 | 51.287         | 54.051          | 58.046            |
| 2023 | 51.426         | 54.663          | 59.341            |
| 2024 | 51.565         | 55.275          | 60.636            |
| 2025 | 51.704         | 55.887          | 61.930            |
| 2026 | 51.844         | 56.499          | 63.225            |
| 2027 | 51.983         | 57.111          | 64.520            |

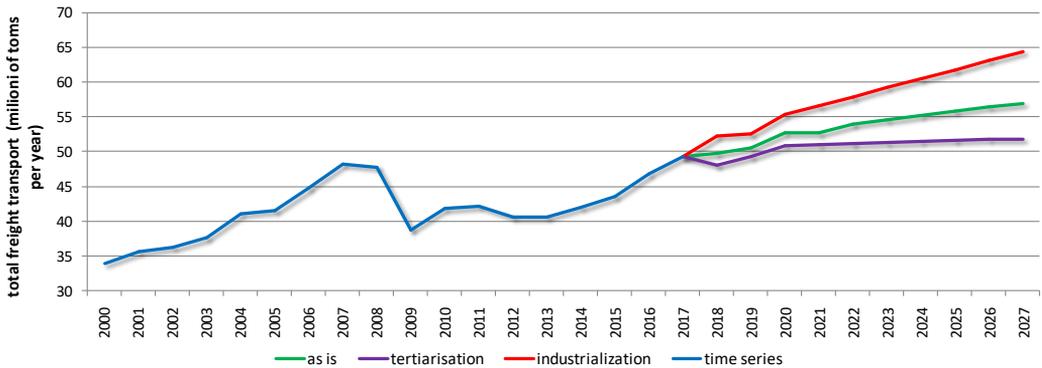


Fig. 18. Total tons of goods transported at the Brenner pass (millions of tons per year) - time series for the period 2000-2017 (iMONITRAF!, 2018) (DG Move - Swisse OFT, 2019) data source - forecast values for the period 2018 - 2027

Higher values are estimated for the industrialization scenario, for which the capacity threshold is expected to be reached by 2022. It is clear that the absence of capacity constraints in the model leads to estimated values which may exceed the threshold value. The values estimated for the tertiarisation scenario are lower, with 52 million tons transported per year in 2027. Despite being below the capacity threshold of 58.4 million tons per year, this value shows a significant saturation of 89%.

## 5. Conclusions

Compared to the some complex articulation of IO modelling, which can hinder their concrete use as decision support in the planning of transport infrastructures (Mauro & Pompigna, 2020), this paper propose a macro-level IO approach (Alises & Vassallo, 2016), which relates directly the quantities of goods transported along an infrastructural corridor with the functioning of the economic system, representing the latter through an SRIO model. This simplified model can be directly applicable by technicians and decision makers, in compliance with some simple and useful criteria for a practice-ready model (Pompigna & Rupi, 2018): reliable input data availability for their calibration and validation; few requirements in the specification and calibration process; highly implementability and usability without having an in-depth statistical training; highly implementability and usability without having an in-depth modelling/programming skills; good compromise between forecasting accuracy and practical usability.

The IO corridor model was used for freight transport analysis at the Brenner trans-Alpine corridor, considering all transport systems (road and rail) serving freight traffic demand. The model considers the annual volume of goods in transit through the Brenner pass and assumes the entire Italian economic system as the reference region for the SRIO model.

Using the IO tables of the Italian economy for the years 2000 to 2014 from WIOD 2016 database and the time series of tons of goods annually transited through the pass, both homogeneously disaggregated with a 9-sector economy system by Italian international trade data, the components of the traffic intensity vector at the Brenner by year have been estimated.

The IO model expressed in matrix form was verified and validated by on-sample predictability analyses of production and tons transported (by sector and total), showing good predictability levels, especially in total terms between 2000 and 2014. The model was used to validate the out-of-sample forecasts for the years 2015-2017 for the total production and for the tons transported at the Brenner based on the actual final demand. The forecast for the total production with the hypothesis of a multiplier matrix that is constant at 2014 values were satisfactory - confirming the actual scarce influence by the production structure variability (i.e., technical coefficients). The forecast of the tons of goods transported appeared strongly conditioned by the assumption of constant traffic intensities, with respect to 2014 values. The assumption of variable intensity factors, obtained as a forecast based on the time trend of the last three

years with available data (2012–2014), showed a substantial improvement, in the comparison between measured data and estimates for annual tonnages.

Therefore, the model calibrated for 2014 was used for the medium-long term forecast between 2018 and 2027, i.e., until the completion of the BBT works, considering the trend in the final demand. Also in this case, a time trend was assumed for the components of freight traffic intensity in the period 2018–2020, and therefore a constant level between 2021 and 2027. The forecasts were formulated for three scenarios, characterized by different allocation of the change in the final demand: the as-is scenario, with a distribution congruent to that of 2014; the industrialization scenario with a distribution of the demand change only on the sectors with high impact on freight traffic; the tertiarisation scenario, with the distribution of all the variation on the non-freight transport sector (i.e., services).

At 2027, the year of completion of the BBT works, in the as-is scenario the tons transported on the road and rail system amounted to 57.11 million tons per year, with a saturation level of 98% compared to the capacity of the road and rail corridor in (Mauro & Pompigna, 2019). For the industrialization scenario, the greater flows of goods driven by final demand have achieved freight values above capacity as early as 2022. Lower values were estimated for the tertiarisation scenario, however with high values of saturation at 2027 and equal to 89%.

The model specification and its application for the Brenner case study highlights the possibility of a concrete use of an IO macro approach, appropriately validated on the basis of historical data, to perform freight traffic analysis and forecasts in a corridor context. In this sense, in fact, the IO perspective appears to be directly applicable using available data relating to the macroeconomic context and the transport system to provide useful elements for the planning of transport infrastructures. Furthermore, this study appears as a starting point for further developments and it may be focused on: a multiregional specification of the model (considering several regional economic systems instead of the single and aggregate one); a multivariate modelling of the dynamics of the modelling parameters (i.e., technical coefficients and traffic intensity factors); a

structural decomposition analysis to isolate and analyze the factors that condition the traffic demand along the corridor over the time.

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