MODELLING FREIGHT DEMAND AT A NATIONAL LEVEL: THEORETICAL DEVELOPMENTS AND APPLICATION TO ITALIAN DEMAND

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1. INTRODUCTION

Literature concerning freight demand simulation models is wide and well-established: some state of the art studies can be found in Daugherty (1979), Harker and Friesz (1986), Picard and Nguyen (1987), Zlatoper and Austrian (1989), Mazzarino (1997), Regan and Garrido (2002). All of them, even if within quite different approaches, classify freight models in reason of the geographical dimension of interest (international, national, inter-city, urban), the simulated choice dimensions (economy and/or transport) and the type of approach (behavioural or descriptive).

At the national level, available freight demand models are based on the integration of macroeconomic models, for the estimation of generation and spatial distribution of freight flows, and transportation models, for mode and route choice evaluation. These dimensions are strictly connected since, from one hand, freight flows represent a consequence of the interrelation between supply and demand of good/services in the market and, from the other hand, localization of firms and selling markets depends on the transportation level of service attributes. Consequently, a correct simulation of this interrelation represents the main issue in freight demand modelling at a national level.

This paper proposes some theoretical developments on national freight demand simulation. In detail, a multi-regional input-output (MRIO) model with elastic trade coefficients and a consignment mode choice model are presented as improvement of the Italian model system for the simulation of freight national demand, which has been eventually applied for both short and long term analyses.

MRIO models allow to simulate the quantity of goods produced and traded among regions, through an explicit representation of the interdependence of different economic sectors. The first theoretical development regards MRIO model structure. For this aim, an overview of MRIO models available in literature is presented, focusing attention to the different hypotheses underlying these models and showing as they can all be derived from the row-column balance in the regional input-output (i-o) table. The second theoretical development is referred to trade coefficients, which represent a fundamental part of MRIO model. At first, it is shown as trade coefficients expressing respectively trade inside the region and trade from abroad can be directly calculated from i-o tables. Then, a correction procedure for all the other trade coefficients, which are usually available by a source not consistent with i-o tables, is proposed. Moreover, the hypothesis of elasticity of trade coefficients with respect to transportation system attributes is usually introduced in long term forecasts, in order to simulate the influence of changes in generalized transport costs not only on modal split but also on freight production and distribution. Therefore, an overview on MRIO models with elastic trade coefficients is presented and an original random utility model for trade coefficient simulation is specified and estimated. These improvements lead to a MRIO model with elastic trade coefficients and endogenous international import, which allows the calculation of the vector of production and of the freight flows as the solution of a bi-level fixed point problem.

With reference to modal choice, a random utility model simulating mode choice for each individual consignment is specified and estimated on the basis of an available database of interviews to Italian firms and shippers. The model provides eight different consignment classes deriving from the combination of two commodity classes, that is perishable and non-perishable, and four weight classes; moreover, perishable consignments are further segmented in containerized or not containerized consignment, and non-perishable are further segmented on the basis of the ratio value/weight and the consignment frequency.

Finally, through the application of the whole model system to the Italian case, a short and long term analysis of freight demand is carried out, analyzing some different policies.

2. AN OVERVIEW OF MRIO MODELS

The macroeconomic choice dimensions in freight demand modelling at a national level are generation and distribution. They might be simulated separately, as often occurs for passenger demand simulation, or jointly through a direct evaluation of origin-destination matrices segmented per region and per sector. Some theoretical and operative aspects suggest a preference towards the latter type of model category. The most important joint generation/distribution models are gravitational models, equilibrium models (Spatial Price Equilibrium and Spatial Computable General Equilibrium) and input-output models; a comparison of these approaches is presented in Roson (1993). The Italian national freight model system is based on models of the last category, which is therefore presented in detail in this section.

The multi-regional input-output models are based on the representation of the productive structure of a region through the i-o table, proposed by Leontief (1936). Some theoretical and operative details on this fundamental instrument of economic analysis can be found in specialized tests, such as Polenske (1980) and Miller and Blair (1985)[1]. Reading i-o table by column provides information about availability of goods of the sector m in the region i, determined by the sum of internal production $X^m{}_i$ and of regional/international imports, respectively $J_{REG}{}^m{}_i$ and $J_{EST}{}^m{}_i$. Production $X^m{}_i$ is given in turn by the sum of the value $K^{nm}{}_i$ of the goods of each sector n needed for the production of m in i. Analogously, reading i-o table by the generic row n provides the demands for goods of the sector n in i, given by production re-usages (variables $K^{nm}{}_i$), final demand $Y^n{}_i$ and regional/international export, $Y_{REG}{}^n{}_i$ and $Y_{EST}{}^n{}_i$ respectively. The introduced variables are summarized in the following Figure 1.

Figure 1 – Scheme of a regional input-output table.

Region *i*		*Sectors of production* S1	S2	S3	S4	Final demand	Regional export	International export
Sectors of production	S_1	…	…	…	…	…	…	…
	S_2	…	…	…	…	…	…	…
	S_3	…	$K^{32}{}_i$	…	…	$Y^3{}_i$	$Y_{REG}{}^3{}_i$	$Y_{EST}{}^3{}_i$
	S_4	…	…	…	…	…	…	…
Added value		…	…	…	…			
Value of production		**…**	$\mathbf{X^2{}_i}$	…	**…**			
Regional import		…	$J_{REG}{}^2{}_i$	…	…			
International import		…	$J_{EST}{}^2{}_i$	…	…			

Consequently, row-column balance represents the equilibrium between availability of goods of a certain sector m in a region i, given by the sum of internal production and regional/international imports, and its total demand, given by intermediate/final consumption and regional/international exports:

$$X^m{}_i + J_{REG}{}^m{}_i + J_{EST}{}^m{}_i = \Sigma_n K^{mn}{}_i + Y^m{}_i + Y_{REG}{}^m{}_i + Y_{EST}{}^m{}_i \qquad (1)$$

Transport applications requires the calculation of production variations due to changes both in final demand and in transportation supply, with a demand driven approach; a symmetric supply driven approach can be adopted, for details see Miller and Blair (1985). All the demand driven MRIO models available in literature can be derived from the balance (1). For this aim, two types of coefficients are introduced, the technical coefficients $a^{mn}{}_i$ expressing the value of goods of sector m needed for the production of one value unit of goods of sector n in the region i:

$$a_i^{mn} = \frac{K_i^{mn}}{X_i^m} \qquad (2)$$

and the trade coefficients, which take into account the different spatial origins (internal, regional, international) of goods/services used in each region. All the available MRIO models share the definition (2), while they use different definitions of trade coefficient, as shown below. IRIO (inter-regional i-o) model, proposed by Izard (1951), introduces a trade coefficient $t^{mn}{}_{ji}$ expressing the percentage of goods of sector m produced in the region j and used for the production of n in region i. Actually, no applications of this model to real contexts are available since, for some economic reasons, percentages $t^{mn}{}_{ji}$

cannot be observed and measured. Therefore, Chenery (1953) and Moses (1955) introduce a simplification in Izard's model through the MRIO (multi-regional i-o) model, in which the acquisition percentages are hypothesized independent from the destination sector, that is $t^{m}_{ji} = t^{mn}_{ji}\ \forall\ n$. In this way, the estimation of trade coefficients is simplified since only knowledge of trade flows of sector m between j and i and not the sectors of destinations of these flows is required.

Some different MRIO model formulations can be derived, depending on some assumptions that can be introduced on foreign imports and exports; in detail:
- foreign exports can be satisfied either by the only internal production or by both internal production and imports;
- foreign imports can be hypothesized fixed (exogenous) or variables (endogenous): an increase in final demand is satisfied by the only increase of the internal production in the former assumption, and by an increase of both internal production and foreign import in the latter assumption;
- foreign imports, if exogenous, can be considered either aggregate, that is represented as a further amount of internal production, or disaggregate, that is explicitly taking into account how they are re-used for both intermediate and final demand.

A report of all the models which can be derived is presented in Figure 2, where the models are presented in a vectorial form, following Cascetta (2001) notation. For each formulation a bibliographical reference, referred to an exhaustive model treatment or to a significant real application, is reported; note that not all the derived formulations can be found in literature.

Figure 2 – Taxonomy of MRIO models.

			FOREIGN EXPORTS	
			Satisfied by the only internal production	Satisfied by both internal production and imports
FOREIGN IMPORTS	**ENDOGENOUS**		$\mathbf{X} = (\mathbf{I} - \mathbf{TA})^{-1}(\mathbf{TY} + \mathbf{Y}_{EST})$ Paniccià Benvenuti (2002)	$\mathbf{X} = (\mathbf{I} - \mathbf{TA})^{-1}[\mathbf{T}(\mathbf{Y} + \mathbf{Y}_{EST})]$
	EXOGENOUS	Disaggregated	$\mathbf{X} = (\mathbf{I} - \mathbf{TA})^{-1}[\mathbf{T}(\mathbf{Y} - \mathbf{J}_{EST}) + \mathbf{Y}_{EST}]$	$\mathbf{X} = (\mathbf{I} - \mathbf{TA})^{-1}[\mathbf{T}(\mathbf{Y} - \mathbf{J}_{EST} + \mathbf{Y}_{EST})]$ Leontief (1963) Bon (1984)
		Aggregated	$\mathbf{X} = (\mathbf{I} - \mathbf{TA})^{-1}(\mathbf{TY} - \mathbf{J}_{EST} + \mathbf{Y}_{EST})$ Chenery (1953) Moses (1955)	$\mathbf{X} = (\mathbf{I} - \mathbf{TA})^{-1}[\mathbf{T}(\mathbf{Y} + \mathbf{Y}_{EST}) - \mathbf{J}_{EST}]$ Costa (1987) Cascetta (2001)

An organic derivation of all these models starting from equation (1) is described in Marzano (2004). By way of an example, the derivation of the

MRIO model with endogenous foreign imports and foreign exports satisfied by the only internal production is reported below.

In detail, quantities $K^{mn}{}_i$ and $Y^m{}_i$ are in part produced in the region i itself and in part imported from the other regions and from abroad:

internal production:	$t^m{}_{ii}\, K^{mn}{}_i$	and	$t^m{}_{ii}\, Y^m{}_i$	(3)
import from region *j*:	$t^m{}_{ji}\, K^{mn}{}_i$	and	$t^m{}_{ji}\, Y^m{}_i$	(4)
import from abroad:	$t^m{}_{ei}\, K^{mn}{}_i$	and	$t^m{}_{ei}\, Y^m{}_i$	(5)

where the trade coefficient $t^m{}_{ji}$ represents, as previously said, the percentage of goods/services of sector m used in region i for whatever use coming from region j or from abroad e. Therefore, by definition it results:

$$t^m{}_{ei} + \Sigma_j\, t^m{}_{ji} = 1 \qquad (6)$$

where the sum is extended to all the regions. Relations (3)-(5) allow to explode the terms of the equilibrium (1):

$$J_{REG}{}^m{}_i = \Sigma_n \Sigma_{j^1 i}\, t^m{}_{ji} K^{mn}{}_i + \Sigma_{j^1 i}\, t^m{}_{ji} Y^m{}_i = (\Sigma_{j^1 i}\, t^m{}_{ji})(\Sigma_n K^{mn}{}_i + Y^m{}_i) \qquad (7)$$

$$J_{EST}{}^m{}_i = \Sigma_n\, t^m{}_{ei} K^{mn}{}_i + t^m{}_{ei} Y^m{}_i = t^m{}_{ei}\, (\Sigma_n K^{mn}{}_i + Y^m{}_i) \qquad (8)$$

$$\Sigma_n\, K^{mn}{}_i = \Sigma_n\, t^m{}_{ii} K^{mn}{}_i + \Sigma_n\, \Sigma_{j^1 i}\, t^m{}_{ji} K^{mn}{}_i + \Sigma_n\, t^m{}_{ei} K^{mn}{}_i \qquad (9)$$

$$Y^m{}_i = \Sigma_{j^1 i}\, t^m{}_{ji} Y^m{}_i + t^m{}_{ei} Y^m{}_i + t^m{}_{ii} \qquad (10)$$

$$Y_{REG}{}^m{}_i = \Sigma_n \Sigma_{j^1 i}\, t^m{}_{ij}\, K^{mn}{}_j + \Sigma_{j^1 i}\, t^m{}_{ij}\, Y^m{}_j = \Sigma_{j^1 i}\, [t^m{}_{ij} (\Sigma_n K^{mn}{}_j + Y^m{}_j)] \qquad (11)$$

The MRIO formulation can be obtained easily replacing relations (7)-(11) into (1); after some manipulations it results:

$$X^m{}_i = \Sigma_n \Sigma_j\, t^m{}_{ij}\, K^{mn}{}_j + \Sigma_j\, t^m{}_{ij}\, Y^m{}_j + Y_{EST}{}^m{}_i \qquad (12)$$

Finally, introducing the technical coefficients given by relation (2) it follows:

$$X^m{}_i = \Sigma_n \Sigma_j\, t^m{}_{ij}\, a^{mn}{}_j\, X^n{}_j + \Sigma_j\, t^m{}_{ij} Y^m{}_j + Y_{EST}{}^m{}_i \qquad (13)$$

which can be expressed in vectorial form as:

$$\mathbf{X} = \mathbf{TAX} + \mathbf{TY} + \mathbf{Y}_{\mathrm{EST}} \;\rightarrow\; \mathbf{X} = (\mathbf{I} - \mathbf{TA})^{-1}(\mathbf{TY} + \mathbf{Y}_{\mathrm{EST}}) \qquad (14)$$

For details about vectorial formulation see Cascetta (2001). Note that trade coefficients $t^m{}_{ei}$ representative of international trades do not appear explicitely in the model (13)-(14), but influence the other trade coefficient values through constraint (6).

All MRIO models presented in Figure 2 share Chenery-Moses assumption. They are also known as column coefficient models since trade coefficients are defined as acquisition percentages from all the regions and from abroad to the considered region. Polenske (1970) proposed instead a row coefficient formulation, apparently symmetric to the Chenery-Moses, which defines trade coefficients as the destination percentages of goods of a certain sector from a given region to all the regions and to abroad. A third approach is described in Leontief and Strout (1963), who specify a gravitational model where trade flows between two regions is directly proportional to the production of origin region and to the demand of destination region, and is also a function of an impedance, measured through a specific trade coefficient depending both on origin and destination region. A comparison among these approaches has been addressed by Bon (1984), who introduces some mathematical conditions on trade coefficient matrix, needed in order to guarantee a non-negative production prevision, and demonstrates that only the MRIO Chenery-Moses formulation is consistent with that.

Moreover, economic assumptions which i-o approach is based on, have been discussed and criticized by some authors, mainly Bianco and La Bella (1987), Roson (1993), Polenske (1995) and Rose (1995). These critics led to two different research directions. On one hand, theoretical alternative approaches have been proposed and developed in order to overcome i-o limits (dispersed spatial price equilibrium models, computable general equilibrium models and so on); on the other hand, some input-output models which in part overcome the limits of standard MRIO models have been proposed. The main result of the latter research development is the MMMVIO (multi-regional multimodal multi-output variable i-o) proposed by Liew and Liew (1984); it considers elasticity in the productive structure due to both variation in price level and to the assumption of multi-output firm behaviour. The model seems therefore to be very exhaustive from a theoretical point of view but the amount of data needed for its estimations prevents applications to real contexts.

Finally, other two interesting i-o modelling applications for freight demand simulation are quoted. Ishikawa (2001) contribution allows the simulation of the impacts of large transport infrastructures (ports, airports and so on), through the subdivision of the study area in concentric zones with respect to the infrastructure itself. Herrero et al. (2002) contribution is focused on the need to consider, in some application, a spatial disaggregation more detailed than the regional level; their proposal should be considered a disaggregation technique of the regional i-o tables rather than the specification of a more detailed MRIO model, and an application is also shown for a Spanish region.

3. TRADE COEFFICIENT MODELLING

3.1 Correction of trade coefficient matrix

All data needed for the implementation of the models described in the previous section come from regional i-o tables, except trade coefficients which are normally estimated through a statistical survey. First of all, is very important to underline that, actually, two trade coefficients, that is foreign trade coefficients t^m_{ei} and internal trade coefficients t^m_{ii}, can be directly calculated through i-o table values. In detail, from the (8) it results:

$$t_{ei}^{m} = \frac{J_{ESTi}^{m}}{\sum_{n} K_{i}^{mn} + Y_{i}^{m}} \qquad (15)$$

In turn, equation (6) can be written as:

$$t^{m}_{ii} = 1 - t^{m}_{ei} - \Sigma_{j \neq i}\, t^{m}_{ji} \qquad (16)$$

which becomes, in virtue of relations (15) and (7):

$$t_{ii}^{m} = 1 - \frac{J_{ESTi}^{m} + J_{REGi}^{m}}{\sum_{n} K_{i}^{mn} + Y_{i}^{m}} \qquad (17)$$

Secondly, since as said, a separate statistical survey is required for the determination of the remaining trade coefficients, the latter are not consistent with all the other data provided by i-o table: in other words, the equilibrium (1) is not generally satisfied by these data. This circumstance introduces a bias in the MRIO model.

To eliminate this bias, a correction procedure of the trade coefficients is proposed in this paper in order to minimize the distance between the production values respectively provided by the model and by the i-o table, through a generalized least squares (GLS) estimator:

$$\mathbf{T}^{*} = \underset{t \in S_t}{\operatorname{argmin}} \left[\sum_{i,m,j} \frac{(t_{ji}^{m} - \hat{t}_{ji}^{m})^2}{\operatorname{var}[t_{ji}^{m}]} + \sum_{i,m} \frac{(X_{i}^{m}(\mathbf{T}) - \hat{X}_{i}^{m})^2}{\operatorname{var}[X_{i}^{m}]} \right] \qquad (18)$$

where $\mathbf{T}$ is the set of all the trade coefficients, $\hat{t}_{ij}^{m}$ and $\hat{X}_{i}^{m}$ represent values available by source (respectively survey and i-o table), $X^{m}_{i}(\mathbf{T})$ indicates the MRIO model (14) and S_t is the feasibility set of trade coefficients. In this way, the (18) provides a $\mathbf{T^*}$ set which is as closest as possible to that available by source, and which minimizes, at the same time, the distance between production values by model and by source. The feasibility set S_t is made up by relations (6), (15), (17) and by the constraint $t^{m}_{ji} \geq 0\ \forall m, j, i$ given by definition. The solution of the problem (18) through a multidimensional constrained optimization algorithm actually requires a strong computational effort and a considerable amount of time.

Therefore, a simplified correction procedure of the trade coefficients has been adopted, based on the circumstance that the internal trade coefficients (17) represent the most significant part of trade pattern: in other words, the demand of a certain good/service in a region is mostly satisfied with internal production. The first step of the procedure is the calculation of the algebraic difference Δ between the $\hat{t}_{ii}^{m}$ evaluated by sample and the t_{ii}^{m} provided by (17); then, the allocation of Δ among all the other regions with a direct proportionality to $\hat{t}_{ij}^{m}$ values and accordingly to constraint (15) is made following the formula:

$$t_{ji\,\mathrm{corr}}^{m} = \frac{1}{1-t_{ei}^{m}}\left(\hat{t}_{ji}^{m} + \Delta\frac{\hat{t}_{ji}^{m}}{\sum_{i\neq j}\hat{t}_{ji}^{m}}\right) \qquad (19)$$

which takes into account that trade coefficients available by source for Italy are referred only to the internal trade, that is not considering international import/export, and therefore they need to be normalized through the foreign trade coefficient (15). The following Table 1 reports mean percentage difference of production by model and by i-o tables before and after the correction.

Table 1 – Results of trade coefficients correction procedure.

	Before correction	*After correction*
Mean percentage difference of production between model and i-o table	9.90%	5.39%

3.2 Modelling trade coefficients through random utility models

The i-o approach, even if partially overcome by new categories of models as described before, has been applied several times to transportation system analysis, thanks to its simplicity and to the possibility of simulating directly the effects of change in transportation system on economic trade. The most direct approach available in literature reproduces this interaction through a simulation model of trade coefficient (MRIO model with elastic trade coefficients). The study of MRIO model with elastic trade coefficients started in the context of the transportation-land use interaction models; a state of the art in this field can be found in Min et al. (2001) and Timmermans (2003). The first application was provided by Williams and Echenique (1978) with the MEPLAN model, eventually developed by Echenique (1994) himself. Another interesting model is TRANUS, proposed by De la Barra (1989), who introduced firstly a random utility model for trade coefficient simulation.

The basic idea of De la Barra's model, known in literature also as RUBMRIO (random utility based MRIO) model, is to simulate variations in trade coefficients through a discrete choice model. The specification proposed for this aim is the Multinomial Logit:

$$t_{ij}^{m} = \frac{e^{-(b_i^m + d_{ij}^m)/q^m}}{\sum_i e^{-(b_k^m + d_{kj}^m)/q^m}} \qquad (20)$$

where $b^m{}_i$ represents the selling price of goods/services of sector m in region i, $?^m$ is a variance parameter and $d^m{}_{ij}$ the transportation cost of the goods of sector m between regions i and j, normally measured as a mean uncongested travel time between the two regions. Selling price is determined as the sum of the acquisition costs c^n_i of inputs needed for the production of m in region i:

$$b_i^m = \sum_n a_i^{nm} c_i^n \tag{21}$$

In turn, the acquisition cost of a sector n in a given region i can be determined as an average weighted on trade flows between regions of the total acquisition costs of that sector from each region j, given by the sum of selling price of n in j, b^n_j, and transportation cost of n from j to i, d^n_{ji}:

$$c_i^n = \frac{\sum_j N_{ji}^n (b_j^n + d_{ji}^n)}{\sum_j N_{ji}^n} = \frac{\sum_j t_{ji}^n C_i^n (b_j^n + d_{ji}^n)}{\sum_j t_{ji}^n C_i^n} = \frac{\sum_j t_{ji}^n (b_j^n + d_{ji}^n)}{\sum_j t_{ji}^n} \tag{22}$$

where N^n_{ji} indicates the value of goods of sector n traded between j and i and $C^n i$ represents the total amount of goods of sector n in region i.

The fixed point problem represented by equations (20)-(22) has been solved firstly by Zhao and Kockelman (2003), which evaluate its theoretical properties and define the solution existence and uniqueness conditions. Min et al. (2001) introduce in the model (20) a size attribute representative of the economic dimension of each region. Cascetta and Iannò (1998) propose and estimate a descriptive trade coefficient model, where d^m_{ij} is calculated as a mode choice logsum and the production values are introduced in order to reproduce regional attractiveness.

Note that, with respect to the state of the art, the only estimated model was provided by Cascetta and Iannò (1998), but unfortunately it does not consider selling prices. De la Barra (1989) and Min et al. (2001) models, which considers explicitly prices, have not been estimated and therefore information about model's goodness of fit cannot be derived. It is important to underline that equation (21) represents an approximate way to define selling prices as a function of acquisition costs, since it should consider technical coefficients q^{nm}_i in quantity (expressing the quantity of goods of sector n needed for the production of one quantity unit of goods of sector m in the region i) rather than technical coefficients a^{nm}_i in value. Since technical coefficients q^{nm}_i in quantity cannot be estimated through i-o tables, also in this paper equation (21) is used to define selling prices considering the technical coefficients a^{nm}_i as a proxy of q^{nm}_i. This simplified hypothesis could introduce a significant bias in the model, and therefore a deep analysis of this issue needs to be carried out.

As a consequence of all these considerations, in this paper a new trade coefficient model has been specified and estimated including selling prices, transportation costs and some other attributes directly derivable by i-o regional tables. In a first phase, a behavioural model analogous to De la Barra (1989), that is with only selling prices and transportation costs, have been estimated but its low goodness of fit suggested to introduce some different attributes. In detail, the proposed model is a Multinomial Logit model; given a certain sector m and a region of destination j, the systematic utility of the region i is expressed as:

$$V_{ij}^{m} = \begin{cases} b_1^m d_{ij}^m + b_2^m b_i^m + b_3^m Y_{REGi}^m & \text{if} \quad i \neq j \\ b_1^m d_{ii}^m + b_2^m{}_2 b_i^m + b_4^m A_i^m & \text{if} \quad i = j \end{cases} \qquad (23)$$

where $d^m{}_{ij}$ is the logsum of the mode choice model described in the next section and $A^m{}_i$ is the total internal availability of goods of sector m in region i, given by:

$$A_i^m = X_i^m + J_{ESTi}^m - Y_{REGi}^i - Y_{ESTi}^m \qquad (24)$$

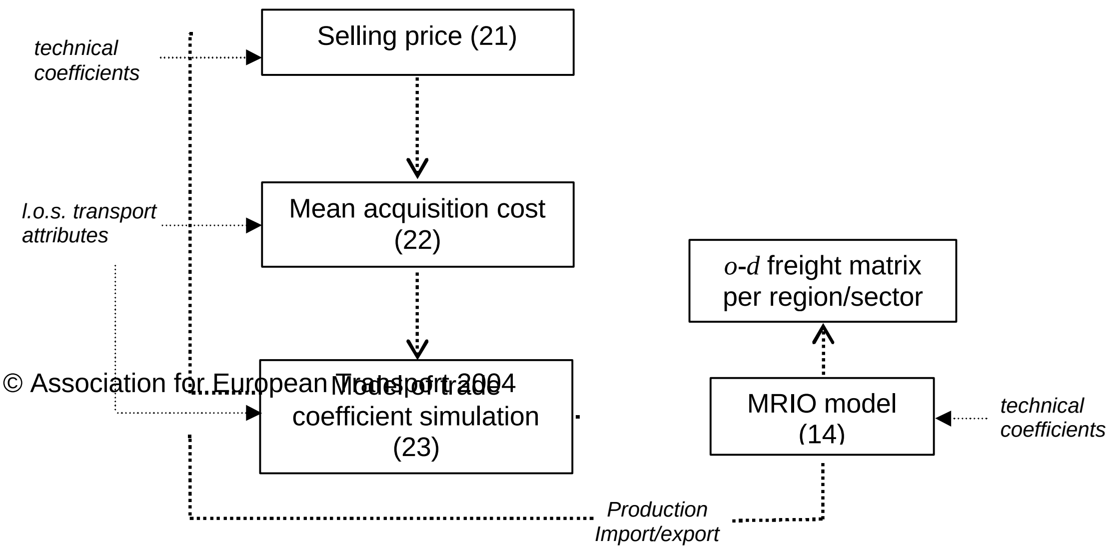
The parameters were estimated with a GLS procedure, in order to minimize the distance between trade coefficients by model and trade coefficients by source corrected as described in the previous section. The results of parameter estimation are shown in the following Table 2, where parameters have been constrained to the expected signs.

Table 2 – Results of trade coefficient model estimation.

	Good sector										
Parameter	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
b_1	-2.466	-0.575	-0.346	-4.032	-1.568	-0.679	-0.613	-1.067	-0.737	-0.431	-1.122
b_2	-3.008	-0.853	0.000	-10.711	-0.561	-2.302	-1.097	-1.454	-1.781	-1.648	-1.789
b_3	0.000	0.000	0.372	0.000	0.160	0.127	0.240	0.000	0.208	0.620	0.167
b_4	1.043	0.290	1.127	1.929	0.410	0.857	0.575	0.338	1.108	4.658	0.690

Note that the presence of the total internal availability and of the regional exports in relation (23) introduces a new feedback between MRIO model and the trade coefficients simulation model (20); therefore, equations (20)-(22) do not represent anymore a fixed point problem in selling prices and trade coefficients as described by Zhao and Kockelman (2003). Consistently with the proposed model specification, the problem can be formulated and solved as a bi-level fixed point problem, as shown in Figure 3; obviously, an analysis of the conditions of solution existence and uniqueness of this bi-level fixed point problem is required.

Figure 3 – Formulation of the double fixed point problem.



4. THE MODE CHOICE MODEL

The proposed mode choice model is a consignment model, that simulates the mode choice for a single consignment. For this aim, the sectors of goods provided by the MRIO model have been firstly grouped into two macro-classes, respectively the perishable/high value (first macro-class) and the not perishable/industrial (second macro-class).

The choice set is made up by the three following modes:

- *train*: traditional service with a single wagon or a group of wagons provided by Trenitalia Cargo (freight division of the Italian national railway company);
- *combined*: transport service of an intermodal transport unit provided by a multimodal railway operator;
- *lorry*: transport service by road

Shipping has not been considered explicitly in the model as a consequence of the unavailability of level of service attributes for that mode; instead, level of service attributes for the other modes were computed on the basis of a network model, and differently for four weight classes (less than 3.5 t, 3.5÷16 t, 16÷30 t, more than 30 t). However, an average of the market share of goods transported by sea was evaluated separately from different data sources for each *o-d* pair and for each macro-class. In this way, an *o-d* matrix of freight using the sea mode can be determined and subtracted from the whole *o-d* freight matrix before applying the mode choice model.

Note that lorry alternative contains normally some different transport services, that is a road transport realized with own vehicles or a transport provided by a carrier with his fleet or a fleet of available vehicles to be rent. Therefore, some different choice sets, characterized by different disaggregation levels of lorry mode, have been tested; the choice set with three alternatives presented above resulted the most significant and convincing. Moreover, the analysis of survey database used in the following model estimation phase showed the choice set to depend also on consignment distance band, since for low distances the only chosen mode is lorry. Consistently with the observed data, in the choice set definition, the train mode is defined unavailable for consignments lower than 100 km and combined mode unavailable for distances lower than 250 km.

The choice probability of mode m for a generic o-d pair is calculated through a Multinomial Logit model:

$$p^w_{mc}[m] = \frac{e^{V^w_{mc\,m}/q}}{\sum_{m'} e^{V^w_{mc\,m'}/q}}$$

where $V^w_{mc\ m}$ is the systematic utility of mode m relative to a consignment of weight class w and macro-class mc, and q is the variance parameter.

The systematic utility have been specified differently for each macro-class, respectively perishable:

$$V^w_{train} = b_1 T^w_{train} + b_4 P^w_{train} + b_5 We_{30}$$
$$V^w_{combined} = b_2 T^w_{combined} + b_4 P^w_{combined} + b_6 Container$$
$$V^w_{lorry} = b_3 T^w_{lorry} + b_4 P^w_{lorry}$$

and not-perishable:

$$V^w_{train} = b_1 T^w_{train} + b_4 P^w_{train} + b_5 We_{30} + b_7\, freq + b_8 Val / We_{20}$$
$$V^w_{combined} = b_2 T^w_{combined} + b_4 P^w_{combined}$$
$$V^w_{lorry} = b_3 T^w_{lorry} + b_4 P^w_{lorry}$$

where T^w_i is the total time [h] for a consignment of class w with the mode i, P^w_i the total cost [€x10^3] for a consignment of class w with the mode i, We_{30} a dummy variable equal to 1 if the consignment weight is>30 t and 0 otherwise, $freq$ a dummy variable equal to 1 if the consignment frequency is<1/month and 0 otherwise, Val/We_{20} a dummy variable equal to 1 if the value/weight ratio of the consignment is>20.000 €/tonn and 0 otherwise, $Container$ a dummy variable equal to 1 if the good is containerized and 0 otherwise.

The parameters of the proposed model have been firstly estimated through a maximum likelihood method, using a database of more than 600 surveys made in Italy in the context of the second “Progetto Finalizzato Trasporti” realized by the National Research Council (CNR). The model has been also validated through statistical tests on parameters significance (test t-ratio) and model goodness of fit (test r^2, Ben-Akiva and Lerman 1985). Numerical results are shown in Table 3, separately for each macro-class (Mc_1 perishable, Mc_2 non perishable). Estimation results show that all the parameters are statistically significant and the values of the reciprocal substitution ratios consistent with those expected. The values of time are greater with respect to those generally encountered in the passenger transport, as a consequence of the average high value of the goods transported. Moreover, the positive value of high weight We_{30} and high value Val/We_{20} attributes indicates a greater competitiveness of train mode for consignment with these characteristics. Obviously, the main attribute influencing combined mode choice is the presence of a container which makes the handling feasible and cheap in the logistic platforms.

Table 3 – Disaggregated estimation of the mode choice model

	Parameter	Alternative	Unit	Mc_1	t-ratio	Mc_2	t-ratio
b_1	*Train time*	Train	Hours	-0.07	*-6.10*	-0.05	*-6.40*
b_2	*Combined time*	Combined	Hours	-0.44	*-7.00*	-0.33	*-7.40*
b_3	*Lorry time*	Lorry	Hours	-0.23	*-4.60*	-0.12	*-4.20*
b_4	*Cost*	Generic	€ * 10^3	-2.30	*-2.00*	-1.24	*-1.90*
b_5	*Weight (>30 tonnes)*	Train	0/1	3.84	*2.80*	2.59	*3.30*
b_6	*Container*	Combined	0/1	5.29	*3.30*		
b_7	*Frequency*	Train	0/1			1.63	*2.00*
b_8	*Specific value (> 20*10^3 €/tonn)*	Train	0/1			3.63	*4.10*
Ln(0)					-187		-161
Ln(b)					-42		-57
r^2					0.78		0.64

The parameters of the mode choice model have been corrected also with an aggregate correction procedure, analogously as in Cascetta and Iannò (1998) paper, on the basis of interregional freight flows data provided by the National Statistic Institute (ISTAT). The correction results are shown in the following Table 4.

Table 4 – Aggregated estimation of the mode choice model

	Parameter	Macro-class I		Macro-class II	
		Initial	*Final*	*Initial*	*Final*
b_1	Train time	-0.074	-0.081	-0.053	-0.049
b_2	Combined time	-0.444	-0.309	-0.329	-0.129
b_3	Lorry time	-0.238	-0.260	-0.120	-0.140
b_4	Cost	-2.302	-2.235	-1.243	-1.206
b_5	Weight (>30 tonnes)	3.839	3.687	2.592	2.692
b_6	Container	5.292	5.451		
b_7	Frequency			1.629	1.678
b_8	Specific value (> 20*10^3 €/tonn)			3.632	3.741
	€/h train	*€ 16.57*	*€ 18.64*	*€ 22.14*	*€ 21.13*
	€/h combined	*€ 99.68*	*€ 71.36*	*€ 136.75*	*€ 55.36*
	€/h lorry	*€ 53.35*	*€ 60.06*	*€ 49.84*	*€ 59.73*
	Goal function	*1.002*	*0.024*	*0.924*	*0.064*

From the operative point of view, the specified mode choice mode introduces 24 demand segments, 8 for perishable goods (4 weight classes per 2 container options) and 16 for not perishable (4 weight classes per 2 frequency options per 2 value/weight ratio options). In order to apply the mode choice model and compute *o-d* freight demand for each mode and segment, the whole *o-d* freight demand has been therefore segmented with the sample enumeration method (Ben-Akiva and Lerman 1985).

5. SHORT AND LONG TERM SIMULATIONS

The models presented above have been settled into the Italian system of model for freight demand simulation, described in Cascetta (2001), which has been eventually applied for some both short and long term simulations. By way of an example, some results are presented in the following.

5.1 Short term runs

The following Table 5 shows the results of base scenario simulation, segmented by mode and distance band.

Table 5 – Base scenario results

Base scenario [tonn * 10^3]				
Distance (km)	*Train*	*Combined*	*Lorry*	*Total*
0-100	0	0	905,065	**905,065**
100-250	1,553	0	200,491	**202,044**
250-500	2,843	3,390	91,713	**97,946**
500-750	1,196	1,093	29,030	**31,319**
750-1000	910	1,142	15,616	**17,668**
>1000	625	842	6,884	**8,351**
Total	**7,127**	**6,467**	**1,248,799**	**1,262,393**

The results underline that almost all freigth demand is transported by road, with a modal share for lorry equal to 94%. More than the half of these trips is essentially intra-regional, with a mean covered distance of about 100 km; note that for this particular market there are no feasible competitors. The supremacy of road transport decreases as the consignment distance increases; in detail, combined transport results very attractive for distances greater than 750 km and for weight classes higher than 30 t. Moreover, some short period runs have been made hypothesizing changes in transportation level-of-service attributes, in order to simulate possible changes in freight transport supply. The result analysis allows to underline some interesting remarks about freight demand elasticity to some different policies; the following Table 6 presents some examples.

Table 6 – Short term results

+10% lorry time [tonn * 10^3]				
Distance (km)	*Train*	*Combined*	*Lorry*	*Total*
0-100	0	0	905,065	**905,065**
100-250	1,633	0	200,411	**202,044**
250-500	3,091	3,649	91,206	**97,946**
500-750	1,433	1,349	28,537	**31,319**
750-1000	1,145	1,487	15,036	**17,668**
>1000	848	1,183	6,321	**8,352**
Total	**8,150**	**7,668**	**1,246,576**	**1,262,393**
% difference	**14.35%**	**18.57%**	**-0.18%**	

-10% combined time [tonn * 10^3]				
Distance (km)	*Train*	*Combined*	*Lorry*	*Total*
0-100	0	0	905,065	**905,065**
100-250	1,544	0	200,500	**202,044**
250-500	2,803	4,629	90,514	**97,946**
500-750	1,147	1,784	28,389	**31,320**
750-1000	852	1,930	14,886	**17,668**
>1000	561	1,523	6,268	**8,352**
Total	**6,907**	**9,866**	**1,245,622**	**1,262,393**
% difference	**-3.09%**	**52.56%**	**-0.25%**	

-10% train time [tonn * 10^3]				
Distance (km)	*Train*	*Combined*	*Lorry*	*Total*
0-100	0	0	905,065	**905,065**
100-250	2,373	0	199,671	**202,044**
250-500	4,574	3,329	90,043	**97,946**
500-750	2,044	1,035	28,241	**31,320**
750-1000	1,612	1,071	14,985	**17,668**
>1000	1,175	767	6,409	**8,351**
Total	**11,778**	**6,202**	**1,244,414**	**1,262,393**
% difference	**65.26%**	**-4.10%**	**-0.35%**	

Short term results confirm that train and combined modes could be competitive with respect to lorry mode only on high distances. Note that percentage decerases observed with reference to lorry mode are very low because its market share is very high, however a greater effect can be observed improving the alternative modes than penalizing lorry itself. The analysis of short term runs segmented per macro-class underlines, as expected, a greater elasticity of the perishable goods to changes in time attributes.

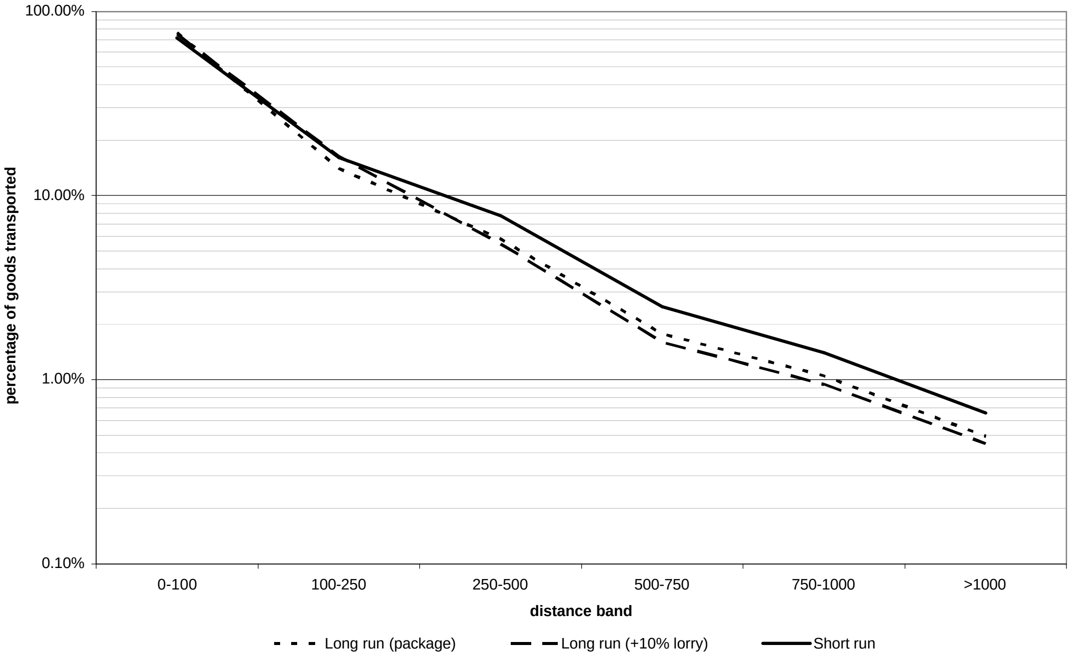
5.2 Long term runs

With reference to long term analysis, the results show a strict connection between variations in level-of-service attributes and changes in the mean distance of the regional trades. In other words, a decrease in accessibility pushes the generic region to purchase goods in closer regions, and therefore the mean distance covered by the consignments will also decrease, and vice versa.

This is shown by the following Figure 4, which reports the % distribution (in a logarithmic scale) of the goods transported among band distances: note that, in the long term, policies penalizing lorry mode determine a percentage reduction of goods transported increasing with the distance band.

Concerning the production level, a decrease in accessibility pushes regions with high import level to reduce import and increase their production level. Consequently, the production of the main export regions tends to decrease.

Figure 4 – Comparison between short and long term results.



6. CONCLUSIONS

In this paper a multi-regional input-output (MRIO) model with elastic trade coefficients and a consignment mode choice model have been presented as improvements of the Italian model system for the simulation of freight national demand; then, some short and long term runs have been proposed and analyzed. The results show the system of models to be flexible and reliable in simulating the interaction between transportation system and economic pattern of a nation.

Some further research developments are also introduced with reference to trade coefficient simulation, that is to analyze the mathematical properties of the described double fixed-point approach, and to selling price determination, that is to address the difference between technical coefficients in value and in quantity.

NOTES

[1] The estimation of an input-output table requires the implementation of a gravitational model, which contains also transportation level of service attributes: an operative methodology is described in Paniccià and Benvenuti (2002). Moreover, in order to obtain an equilibrium between row and column sums a *balance* procedure is needed; the main used procedures are the SCM

proposed by Stone (1942) and the RAS by Bacharach (1970). A modified RAS procedure, proposed by Inamura and Srisurapanon (1998), represents the basis of a particular input-output model for freight flow forecasts.

ACKNOWLEDGMENTS

The authors wish to thank Dr. Gianluca Cutrera for the help provided in specification and estimation of the mode choice model.

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