

LONG-TERM IMPACTS OF URBAN LAND USE AND TRANSPORT POLICIES: SIMULATION AND ASSESSMENT

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1. INTRODUCTION

Spatial economic and transport systems are mutually interacting. The transport system plays an important role in the economy and in the spatial organization (geography) of an area (national, regional, urban), affecting activity location, production levels and trade patterns. Conversely, the spatial economic system affects travel demand characteristics.

In a generic system we may identify components and interactions, which may be endogenous or exogenous. Regarding the spatial economic system, the endogenous components are activity generation and location, which mutually interact. The exogenous component is transport accessibility, which influences activity location. Regarding the transport system, the endogenous components are transport demand and supply, which mutually interact. The exogenous components are the level and spatial distribution of activities, which influence travel demand. Fig. 1 shows the components and interactions of the two systems.

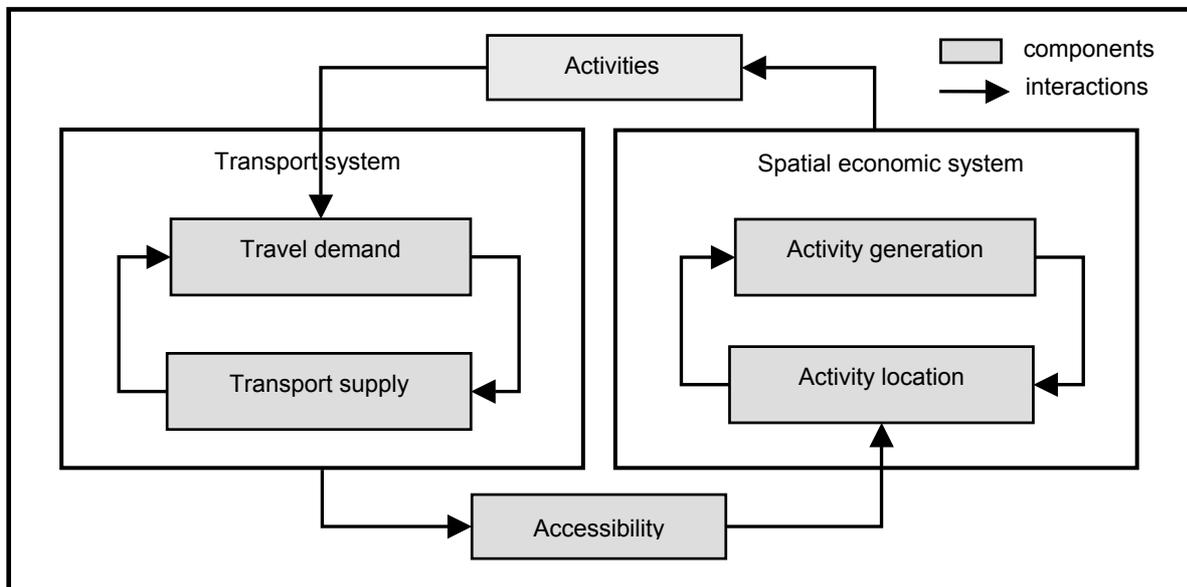


Fig. 1. Spatial economic and transport systems: components and interactions

Considering the three planning dimensions (Russo and Rindone, 2007), in the time dimension the process of interaction between the spatial economic system and the transport system has a strategic scale; in the study-in-depth dimension, it has directional scale (in which objectives and strategies are defined); in the spatial dimension, it may be related to two different scales. At the national scale, attention is

devoted to estimating the competitiveness of the different activities, defining production levels and location convenience. As the economic component is dominant over the land use component, we define a *National Economy Transport Interaction (NETI)* process. At the urban scale, the focus is on analysing the effects of transport mobility on the spatial organization of an area (e.g. location of residential, service and production activities) with subsequent land use. As the spatial component (land use) is dominant over the economic one, we define a *Land Use Transport Interaction (LUTI)* process.

The analysis of interactions between the spatial economic and transport systems requires the support of models and methods from both economics and transport engineering.

The paper presents a survey on Spatial Economic (SE) models, focusing in particular on the category of integrated macroeconomic generation-location models. Such models refer to a Multi-Regional-Input-Output (MRIO) framework and have different specifications in the literature according to the spatial scale used.

The paper is structured as follows. Section 2 presents a literature review of SE models at national and urban scales. Section 3 gives a general formulation of Spatial Economic Transport Interaction (SETI) models: first, two formulations of each modelling component related respectively to the spatial economic system and to the transport system are reported separately; finally, the general formulation of a SETI model is presented. In section 4, models are specified according to the national or urban scale of analysis. The last section reports our research agenda.

2. LITERATURE REVIEW OF SPATIAL ECONOMIC MODELS

In the context of the NETI process (national scale), we define *economic models* as those which generally simulate individual or aggregate behaviour of consumers and producers, estimating trade, production and consumption levels (and location) of goods and services. In the context of the LUTI process (urban scale), we use *land use models* to define those which generally simulate behaviour of residents, employees and firms, estimating the level and location of residential and economic activities and land use.

For both types of models, three different classes of modelling components may be considered:

- *generation models*, which provide an aspatial estimation of production and consumption levels;
- *location models*, which provide a spatial distribution of production and consumption;
- *integrated generation-location models*, which jointly estimate the levels and spatial distribution of production and consumption.

Generation models may be:

- *microeconomic*, that simulate individual (disaggregate) behaviour through individual demand and production theory;
- *macroeconomic*, that simulate aggregate behaviour through variables and relationships that exist among them.

Location models may be:

- *gravitational-entropic*, that refer to gravitational theory and to the entropy maximization principle;
- *discrete*, that refer to random utility theory.

Integrated generation-location models may refer to models belonging to the above defined classes, in which transport costs may be:

- *endogenous*, if mutual interactions with the transport system are simulated; in other words, if the transport system affects the location pattern through accessibility and the spatial economic system affects the travel demand pattern (see Fig. 1).
- *exogenous*, if mutual interactions with the transport system are not simulated.

Integrated generation-location models with endogenous transport costs will be termed below as *Spatial Economic Transport Interaction (SETI) models*; if they refer to the national scale we will be defined as *NETI models*, while if they refer to the urban scale they will be defined as *LUTI models*.

Tab. 1 shows a classification of SE models.

Tab. 1. Classification of SE models

	Land use (urban)		Economic (national)	
Generation	Micro	Macro	Micro	Macro
Location	Discrete	Entropic-gravitational	Discrete	Entropic-gravitational
Generation-location (exog)*	Micro	Macro	Micro	Macro
Generation-location (endo)**	Micro (LUTI)	Macro (LUTI)	Micro (NETI)	Macro (NETI)

* exogenous transport costs; ** endogenous transport costs

Among land use models, macroeconomic generation models are derived from economic base theory, initially proposed by Hoyt (1939), who subdivided employment in an urban area into basic and non-basic employment. Basic employment generates, according to a multiplier factor, non-basic employment. Later, Tiebout (1955) and North (1956) proposed a model enhancement, called the regional income model, derived from the assumption that income depends on economic sectors which export goods and services.

Among integrated macroeconomic generation-location models, a distinction is necessary between models with exogenous transport costs and models with endogenous transport costs (LUTI models). A model belonging to the former category was proposed by Lowry (1964), which simulates location patterns of residential and service activities. It consists of two integrated modelling components: a generation model, based on the economic base theory, and a gravity location model. Given the level and location of basic employment, the levels of population and non-basic employment are computed and their spatial distribution is achieved through the gravity model, in which transport costs are exogenously given. Lowry's contribution was of capital importance and several later attempts were made to overcome the original limitations of the model and to extend its applicability.

Garin (1966) improved the Lowry model by casting the entire model in matrix notation. Macgill (1977) presented the Lowry model as an input-output model. Macgill's work marks the first attempt to build a metropolitan Input-Output (IO) model that captures inter-sectoral linkages. Lowry's model was further developed by Putman (1973, 1983, 1991), who proposed two models to locate respectively residents (DRAM, Disaggregate Residential Allocation Model) and employment

(EMPAL, Employment Allocation Model) across zones.

Several integrated generation-location macroeconomic models with endogenous transport costs (LUTI models) have been proposed in the literature: TRANUS (de la Barra, 1989; Modelistica, 2000), MEPLAN (Echenique and Hunt, 1993; Abraham and Hunt, 1998), IRPUD (Wegener, 1998), DELTA (Simmonds and Still, 1998; Simmonds, 2000). They simulate transport and activity systems by means of market mechanisms, where demand and supply interact, simultaneously providing prices and quantities. In the transport model, user behaviour is simulated through demand models which estimate emission, mode and path choices. These choices are driven by utility, which include transport costs provided by a congested network model. Demand-supply interaction is simulated through an assignment model, which estimates transport costs (prices) and flows (quantities) on network. If the available supply (transport facilities and services) is limited, congestion costs arise which bring the transport system to an equilibrium condition. In the land use model, household and firm behaviour is simulated through an activity generation model which estimates demand (consumption) levels of activities (population, employment, land) and an activity location model which simulates where activity supply (production) is located across zones. Location choices are addressed by utilities, consisting of a supply price plus transport cost. After demand-supply interaction, supply prices and production quantities in each zone are estimated. Due to supply constraints (e.g. restrictions in available land), rent could be generated which brings the activity system to an equilibrium condition.

Integrated generation-location microeconomic models with exogenous transport costs focus on consumers (households and firms) and producers (landowners and employers). Their behaviour is driven by market mechanisms, in which consumers maximise their utility subject to budget constraints and producers maximise their benefits, generating an equilibrium pattern of land rent. The pioneering work of Von Thünen (1826) explained the effect of transport costs on activity locations and land prices. Wingo (1961) and Alonso (1964) adapted Von Thünen's monocentric market proposition for the urban case by adding consumer budget constraints. Further developments were made by the Muth (1968) and Mills (1969) models. After the proposition of random utility theory (Domencich and McFadden, 1975), Anas and Duann (1984) proposed an integrated model which brings land rent in line with residential location and travel demand modelling.

Integrated generation-location microeconomic models with endogenous transport costs (LUTI models) concern the development of spatial computable general equilibrium models able to clear land, labour and goods markets. Trade flows generate both freight and passenger travel demand. The literature concerning the class of microeconomic generation-location models is very rich and may be included in the broad discipline called *urban economics*. As an example we recall the papers of Anas and Kim (1997) and Anas and Liu (2007).

In the sphere of macroeconomic (national) class of models, the basic concepts of generation models may be found in Keynes's theory (Keynes, 1936), which introduced the principle of effective demand, whereby production is determined by consumption. Leontief (1941) proposed a generation model with an Input-Output (IO) framework to simulate inter-dependencies between economic sectors through fixed technical coefficients. Further theoretical developments from the original IO structure, able to reproduce the spatial representation of an economy, were later proposed (Isard, 1951; Chenery, 1953; Moses, 1955). They introduced trade coefficients to

calculate exogenously interregional trade patterns and locate production across zones, although they did not specify any model to estimate them. From the above theoretical assumptions, several models were proposed in the literature, which may be grouped in the Input-Output Multi-Regional (MRIO) category, which incorporates a location model into the IO framework in order to obtain an endogenous estimation of trade coefficients. MRIO models may be subdivided into models with exogenous transport costs and models with endogenous transport costs (NETI models). Models with exogenous transport costs are the models proposed by Leontief and Strout (1963) and Wilson (1970a), which implemented an entropic-gravitational location model. NETI models refer to the same paradigms as the LUTI models previously described. Early models implemented location models belonging to the entropic-gravitational category. After the proposition of random utility theory (Domencich and McFadden, 1975), Cascetta et al. (1996) proposed an MRIO model where trade coefficients were estimated through a discrete location model. Several papers were presented in which the economy and freight travel demand at a national scale are simulated (Cascetta *et al.*, 1996; Russo and Conigliaro, 1997; Cascetta and Iannò, 1998; Russo, 2001; Marzano and Papola, 2004; Kochelman *et al.*, 2005). Freight travel demand was estimated through a system of models, which may not belong to the macroeconomic class. The MRIO framework is described in detail in the next section.

Regarding the microeconomic (national) class of models, the theoretical background may be found in the Walras theory (1874), with modern modifications and extensions. Its kernel is the concept of market general equilibrium, where all agents belonging to all markets of the economy make mutually consistent plans, such that no agent has incentives to revise his/her plan. In generation models, a transport sector is defined (like any other sector) as that which produces transport services that are used as intermediate inputs by firms or consumed by households. In integrated generation-location models, transport appears as an activity transferring goods and passengers between zones. A state-of-the-art analysis of microeconomic models, which use the general equilibrium approach, is presented in Bröcker (2004).

Location models assume the whole production and consumption levels as exogenous and simulate how they are spatially distributed across zones. Both types of location models, previously defined, may be implemented inside land use and economic models. Several specifications of location models, based on Newton's gravity law, were proposed to estimate activities location and transport demand. Wilson (1967, 1970b) derived location models from entropy maximization procedures. Entropic-gravitational models (called also spatial interaction models in the literature) were extensively used in the works of Putman (1973, 1983, 1991). Discrete location models are theoretically underpinned by random utility theory (Domencich and McFadden, 1975). The literature in this regard is huge: as an example of models for urban scale we recall the papers of Anas and Duann (1984), Cascetta *et al.* (2001), Cascetta *et al.* (2004) and de Palma *et al.* (2007). Some are part of a system of models able to estimate travel demand in the medium-long term.

Some comments regarding the classes of models defined in the survey are presented below. Microeconomic models treat space as a continuous variable, making it impossible to represent geography in all its variety. Modelling more than one market place or centre of employment is very complex, even if much effort has been, and is still, made in this direction. Furthermore, it is impossible to capture

individual behaviour of consumers and producers in the same way as in classical equilibrium theory. This class of model, albeit founded on a strong theoretical basis, appears to encounter severe difficulties analysing real cases. Entropic-gravitational (spatial interaction) models provide an aggregate perspective, since both space and activities are grouped into discrete categories. They are loosely structured from a theoretical point of view: the entropy-maximising method makes no assumptions about the behaviour of consumers and producers involved and no market equilibrium process is guaranteed. The development of macroeconomic models pivots on the potential provided by the MRIO framework, which introduced the dimension of production in relation to the spatial structure. This potential has been translated into concrete application by the introduction of discrete choice modelling. The MRIO framework seems to offer a valuable set of relationships able to bring production levels, location choices and land use in line within travel demand modelling.

3. SETI MODELS: GENERAL FORMULATION

This section presents a general formulation of SETI models. First, two formulations of each modelling component related respectively to the spatial economic system and to the transport system are reported separately. The modelling framework simulating the spatial economic system is represented by a macroeconomic generation-location model, which refers to the MRIO approach. The theoretical evolution that involved MRIO models from the basic concepts to the current formulations is described, focusing especially on variable **T**. The modelling framework related to the transport system consists of a supply model, a demand model and an assignment model. Finally, the general formulation of a SETI model is presented.

3.1. Macroeconomic generation-location models (MRIO framework)

The basic concepts of macroeconomic generation-location models are to be found in Keynes's theory (1936), which introduces the principle of effective demand, whereby production, x , is determined by demand, y . A key element is the idea of a multiplier effect, where, given that production and demand are always balanced, a demand generates a production equal to:

$$x = a x + y \quad (1)$$

where $a (< 1)$ is the marginal propensity to consume.

In the sphere of Keynes's theory, Leontief, in analyzing interdependencies (goods and services exchanges) inside an economic system, found the existence of accounting duplications that influence the calculation of production value. From the information contained in the accounting duplications, he first proposed an IO model (Leontief, 1941), which simulated inter-sectoral linkages inside an economic system, capturing multiplier effects at sector level. The model ensures a balance between production and demand (intermediate plus final) at sectoral level, but it assumes inputs are used in fixed ratios to produce any output through fixed technical coefficients (no input substitution is allowed). Eq. (1) becomes for the IO model:

$$x = A x + y \quad (2)$$

where

\mathbf{x} is the production vector;

\mathbf{y} , the final demand vector;

\mathbf{A} , the technical coefficients matrix.

Generation-location models originate from the integration of the IO approach and location models into an MRIO framework. Spatial disaggregation was necessary in order to take into account that goods and services may be produced and consumed in different regions. In a multi-regional economy internal production and consumption may not be balanced in each region; the balance is reached by considering import and export flows.

Early (first generation) MRIO models assumed fixed technical and trade coefficients (Isard, 1951; Chenery, 1953; Moses, 1955) Trade coefficients, which were determined exogenously to the MRIO model, have different features. Isard's trade coefficients have a destination sector and origin/destination region specification. This assumption leads to the following formulation:

$$\mathbf{x} = \mathbf{C} \mathbf{x} + \mathbf{T} \mathbf{y} \quad (3)$$

with

\mathbf{C} , (regional) technical coefficients matrix;

\mathbf{T} , trade coefficients matrix.

Chenery and Moses's trade coefficients have only an origin/destination region specification. This assumption leads to the following formulation:

$$\mathbf{x} = \mathbf{T} \mathbf{A} \mathbf{x} + \mathbf{T} \mathbf{y} \quad (4)$$

Models (3) and (4) allow to estimate production levels and location across zones and capture multiplier effects both at sectoral and zone level.

3.2. Transport models

The three main components of the transport modelling framework are the supply model, the demand model and the assignment model. In the literature a large variety of models belonging to each component is present (see Fig. 2). Detailed state-of-the-art analyses are presented in Ben-Akiva and Lerman (1984), Ortuzar and Willumsen (2001) and Cascetta (2006).

Supply models are represented by a network model, where graphs may be primary vs. dual and link cost functions may be aggregate (speed-density vs. time-flow relationships) vs. disaggregate (car-following, lane-changing, gap-acceptance models). A general formulation of a (congested) network model consists of a path costs vs. link costs consistency equation (5.a) and of a path flows vs. link flows consistency equation (5.b):

$$\mathbf{g} = \Delta^T \mathbf{c}(\mathbf{f}) \quad (5.a)$$

$$\mathbf{f} = \Delta \mathbf{h} \quad (5.b)$$

with

g, path costs vector;
Δ, link-path incidence matrix;
c, link cost functions vector;
f, link flows vector;
h, path flows vector.

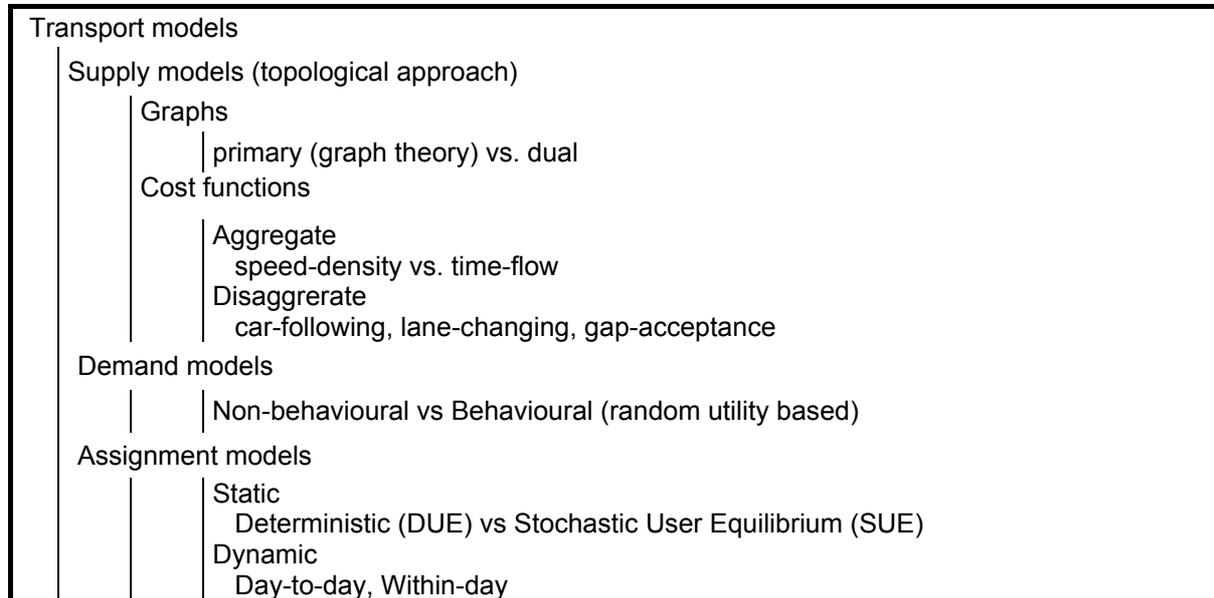


Fig. 2: Classification of transport models

Demand models may be non-behavioural (gravitational-entropic) vs. behavioural (random utility based). A general formulation of a (rigid) demand model with a stochastic path choice model is:

$$\mathbf{h} = \mathbf{P} (\Delta^T \mathbf{c} (\mathbf{f})) \mathbf{d} \quad (6)$$

with

P, probability path choice functions matrix;
d, demand flows vector.

Assignment models may be static (deterministic vs. stochastic), or dynamic (day-to-day vs. within-day). A general formulation of a Stochastic User Equilibrium (SUE) assignment model is reported below:

$$\mathbf{f}^* = \Delta \mathbf{P} (\Delta^T \mathbf{c} (\mathbf{f}^*)) \mathbf{d} \quad (7)$$

$$\mathbf{f}^* \in S_f$$

with

f*, link flows vector at equilibrium;
S_f, set of feasible link flows.

3.3. SE models

In the first generation of MRIO models trade coefficients were estimated exogenously. Later generations allowed endogenous estimation of trade coefficients by incorporating location models inside the MRIO framework. A description of the evolution concerning location models for trade coefficients estimation inside MRIO framework is presented below (Fig. 3).

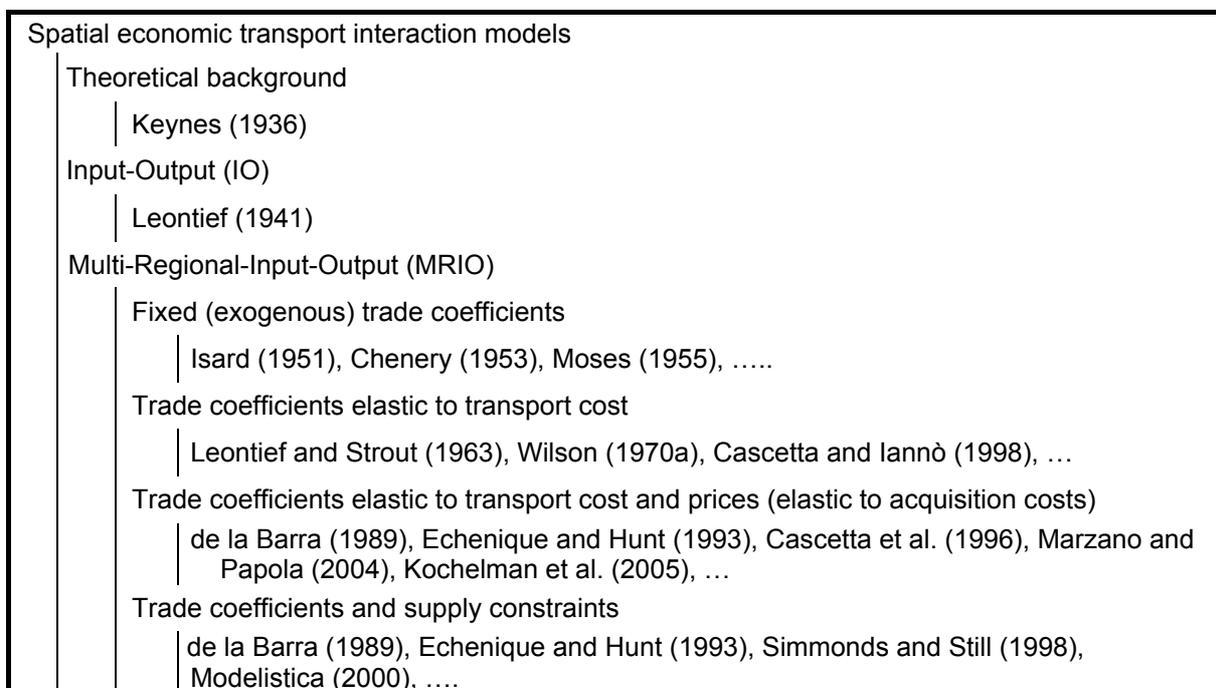


Fig. 3: SE models: classification of location models for trade coefficients estimation

The second generation introduced trade coefficients which were elastic to transport costs (disutilities), estimated through a location model. The approaches adopted for the location model were originally entropic-gravitational and later discrete. The formulation of the model is:

$$\mathbf{x} = \mathbf{T}(\mathbf{V}) \mathbf{A} \mathbf{x} + \mathbf{T}(\mathbf{V}) \mathbf{y} \quad (8)$$

with

\mathbf{T} , trade coefficients functions matrix,

\mathbf{V} , transport costs (disutilities) matrix.

The third generation assumes trade coefficients elastic to transport costs (disutilities) and to selling prices, which are, in their turn, elastic to acquisition costs:

$$\mathbf{x} = \mathbf{T}(\mathbf{V}, \mathbf{p}(\mathbf{q})) \mathbf{A} \mathbf{x} + \mathbf{T}(\mathbf{V}, \mathbf{p}(\mathbf{q})) \mathbf{y} \quad (9)$$

with

$\mathbf{p}(\mathbf{q})$, selling prices function vector;

\mathbf{q} , acquisition costs vector.

In eq. (9) a circular dependence among \mathbf{T} , \mathbf{p} and \mathbf{q} , is present which has been solved as a fixed point problem, defining the solution existence and uniqueness conditions (see more details in the following section).

The fourth generation introduces constraints in the vector of production levels, $\mathbf{x} < \bar{\mathbf{x}}$:

$$\mathbf{x}^* = T(\mathbf{V}, \mathbf{p}(\mathbf{q}), \mathbf{x}^*) \mathbf{A} \mathbf{x}^* + T(\mathbf{V}, \mathbf{p}(\mathbf{q}), \mathbf{x}^*) \mathbf{y} \quad (10)$$

From eq. (10), it emerges that production vector, \mathbf{x}^* , results from the solution of a bi-level fixed point problem.

3.4. SETI model

The SETI model has two interacting modelling components: the transport model and the generation-location model. The transport model is composed by:

- a congested network model, represented by equations (5.a) and (5.b);
- a demand model, elastic to transport costs on the emission and mode dimensions and to trade flows, with a stochastic path choice model

$$\mathbf{h} = \mathbf{P} (\Delta^T \mathbf{c}(\mathbf{f})) \mathbf{d}(\mathbf{F}, \mathbf{V}) \quad (11)$$

with

\mathbf{P} , probability path choice functions matrix;

\mathbf{d} , demand functions vector;

\mathbf{F} , trade flows matrix;

- an assignment model

$$\mathbf{f}^* = \Delta \mathbf{P} (\Delta^T \mathbf{c}(\mathbf{f}^*)) \mathbf{d}(\mathbf{F}, \mathbf{V}) \quad (12)$$

$\mathbf{f}^* \in S_f$

with

\mathbf{f}^* , link flows vector at equilibrium;

S_f , set of feasible link flows.

The generation-location model is composed by:

- a generation model with technical coefficients depending on selling prices

$$\mathbf{y} = \mathbf{A}(\mathbf{p}) \mathbf{y} + \mathbf{y}^e \quad (13)$$

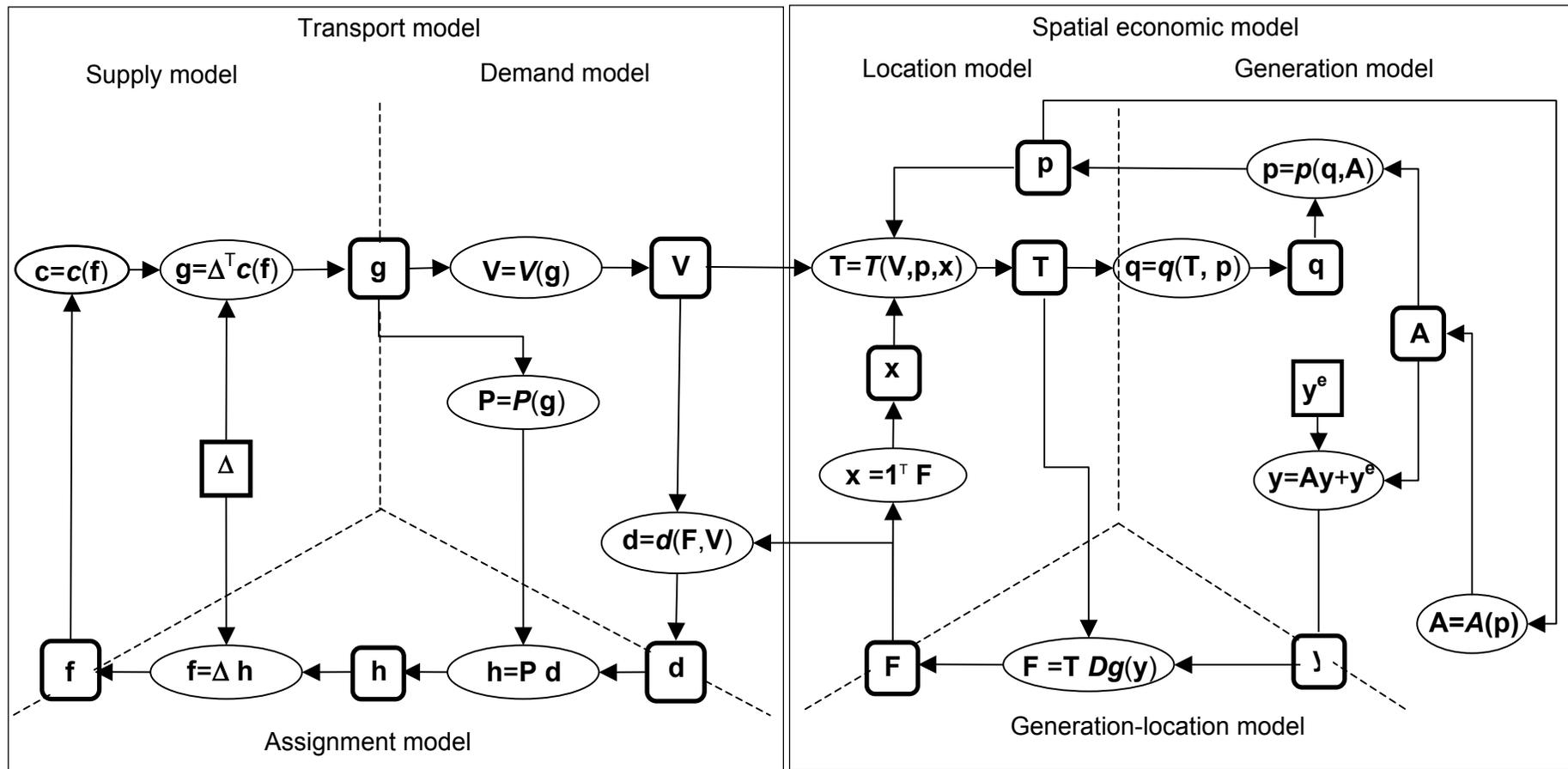
with

\mathbf{y} , activity demand vector (internal end external);

$\mathbf{A}(\mathbf{p})$, technical coefficients functions matrix;

\mathbf{p} , selling prices vector;

\mathbf{y}^e , exogenous activity demand vector;



Legend: \bigcirc model \square exogenous input \square endogenous input/output

Fig. 4. SETI model: components and connections

- a location model for estimating the trade coefficient matrix, \mathbf{T} , which depends on transport utilities, selling prices and production

$$\mathbf{T} = \mathbf{T}(\mathbf{V}, \mathbf{p}, \mathbf{x}) \quad (14)$$

with

\mathbf{T} , trade coefficient functions matrix;

\mathbf{x} , production vector;

- a generation-location interaction model:

$$\mathbf{F} = \mathbf{T}(\mathbf{V}, \mathbf{p}, \mathbf{x}) \mathbf{Dg}(\mathbf{y}) \quad (15)$$

with

$\mathbf{Dg}(\mathbf{y})$, the matrix obtained by arranging the elements of vector \mathbf{y} along the main diagonal.

Finally, the production vector, \mathbf{x} , is obtained from:

$$\mathbf{x} = \mathbf{1}^T \mathbf{F} \quad (16)$$

The combination of eqs. (13), (15) and (16) gives rise to eq. (10).

In both the transport and spatial economic models, the presence of exogenous physical or regulatory constraints gives rise to rents, which reflect the congestion in the transport and spatial economic systems and provide the mechanisms to bring the demand in line with the available supply.

4. GENERATION-LOCATION MODEL SPECIFICATION

As shown in section 3.1, eq. (4) evolved in subsequent more complex formulations, but it may formally be considered as the reference equation to describe the MRIO framework. In relation to eq. (4), different models have been considered in the literature to specify models for estimating variables \mathbf{A} and \mathbf{T} , according to the national or urban scale of analysis.

4.1. National scale

At a national scale, attention is devoted to estimating sector production and consumption levels in each zone (vectors \mathbf{x} and \mathbf{y} respectively) and trade flows (matrix \mathbf{F}), neglecting the land use aspect. The national economic system is discretized into sectors and zones, in which production and intermediate consumption in each zone are generated by exogenous (final) consumption (sub-vector \mathbf{y}^e). The emphasis is laid on primary and secondary economic sectors.

In eq. (4), vectors \mathbf{y} and \mathbf{x} , are specified as follows:

$$\mathbf{y} = [\mathbf{y}^e \mid \mathbf{0} \mid \mathbf{0}]^T$$

$$\mathbf{x} = [\mathbf{0} \mid \mathbf{x}^p \mid \mathbf{x}^s]^T$$

where

\mathbf{y}^e is the sub-vector of exogenous (final) consumption;

\mathbf{x}^p , the sub-vector of primary sector production;

\mathbf{x}^s , the sub-vector of secondary sector production.

Technical coefficients inside matrix \mathbf{A} may be constant if the combination of inputs required to produce outputs is assumed fixed; or variable, if the combination of inputs may be modified due to changes in the economic system. The former assumption implies that the production function has fixed coefficients and it is linear (constant returns to scale). Sector production and consumption may be expressed in value (e.g. Euros) or quantity (e.g. tons).

Trade coefficients of matrix, \mathbf{T} , simulate the location process of economic sectors among zones (regions) of a nation. Each element, t_{ij}^m , is the probability (percentage) that production of sector m locates in zone i , conditional upon being consumed in zone j :

$$t_{ij}^m = \text{Prob} (\text{production } m \text{ locates in } i \mid \text{consumption in } j) \quad (17)$$

Trade coefficients of matrix, \mathbf{T} , have been estimated in the literature through entropic-gravitational or discrete location models. In the early entropic-gravitational specifications (Leontief and Strout, 1963; Wilson, 1970a), trade coefficients depended on production-demand levels in origin-destination zones and on transport costs.

$$t_{ij}^m = A_{.i}^m x_i^m B_{.i}^m y_j^m \exp(-\beta^m c_{ij}^m) \quad (18)$$

with

x_i^m , production of sector m in zone i ;

y_j^m , demand for sector m in zone j ;

$A_{.i}^m = (\sum_j B_{.j}^m y_j^m \exp(-\beta^m c_{ij}^m))^{-1}$

$B_{.i}^m = (\sum_i A_{.i}^m x_i^m \exp(-\beta^m c_{ij}^m))^{-1}$

β^m , parameter to be calibrated.

Some discrete location models were later proposed. As an example, we report a multinomial logit model specification:

$$t_{ij}^m = \exp(V_{ij}^m/\theta^m) / \sum_{k \in N} \exp(V_{kj}^m/\theta^m) \quad (19)$$

with

$V_{ij}^m = p_i^m + c_{ij}^m$, systematic utility of purchasing sector m from zone i to be used in zone j ;

$p_i^m = k_i^m + e_i^m$, selling price of sector m produced in zone i (as sum of a production cost, k_i^m , and a rent, e_i^m);

c_{ij}^m , (non-congested) transport cost of sector m from zone i to zone j .

The explicit dependence of trade coefficients on selling prices was first introduced by de la Barra (1989). More complex specifications of systematic disutility, V_{ij}^m , have been proposed, including attributes such as a "size" term

expressing the (unknown) number of elementary choice alternatives in a zone. As zone i does not purchase inputs locally (i.e. from itself), the selling price, p_i^m , is estimated as the sum of acquisition costs of inputs n needed for the production of output m in zone i , q_i^n , weighted through technical coefficients in zone i , a_i^{nm} :

$$p_i^m = \sum_n a_i^{nm} q_i^n \quad (20)$$

In turn, acquisition costs are expressed as an average across acquisition costs from different zones i , weighted through trade coefficients, t_{ji}^n :

$$q_i^n = (\sum_j t_{ji}^n (p_j^n + c_{ji}^n)) / \sum_j t_{ji}^n \quad (21)$$

Eqs. (19), (20) and (21) define a circular dependence among t_{ij}^m , p_i^m and q_i^n , which has been solved iteratively (de la Barra, 1989; Echenique, 2004). Zhao and Kochelman (2004) formalized the above set of equations as a fixed point problem and defined the solution existence and uniqueness conditions.

The previous considerations hold when production capacity of each sector m in zone i is assumed to be non-limited. If production capacity is assumed to be limited, trade coefficients and production for each zone result from an interaction between demand and production capacity of a generic sector in the same zone.

4.2. Urban scale

At an urban scale, the production-consumption paradigm described for the national scale still holds. However, emphasis is laid mainly on tertiary economic sectors (such as services and commerce), on residential, h , and on land, l , sectors. The urban spatial system is discretized and production and intermediate consumption are generated by exogenous (final) consumption (vector \mathbf{y}^e). In all economic sectors there is a demand for land, l , represented by the vector of zonal available floor-space.

In eq. (4), vectors, \mathbf{y} and \mathbf{x} , are specified as follows:

$$\mathbf{y} = [\mathbf{y}^e \mid \mathbf{0} \mid \mathbf{0} \mid \mathbf{0}]^T$$

$$\mathbf{x} = [\mathbf{0} \mid \mathbf{x}^t \mid \mathbf{h} \mid \mathbf{l}]^T$$

where

\mathbf{y}^e is the sub-vector of exogenous (final) consumption, which may be identified with exports;

\mathbf{x}^t , the sub-vector of tertiary sector production;

\mathbf{h} , the sub-vector connected to socio-economic categories in which the residential sector (households) could be segmented;

\mathbf{l} , the sub-vector of types of available floor-space.

Sector production and consumption may be expressed in value (e.g. Euros) or quantity (e.g. households, employees). Technical coefficients of matrix, \mathbf{A} , simulate the generation process of tertiary, residential and land sectors by

exogenous consumption. Technical coefficients may be constant or elastic. In the literature, one specification presents an elastic technical coefficient connected to land consumption (de la Barra, 1989) in zone j by activity n , $a_j^{l,n}$:

$$a_j^{l,n} = \beta_1^{l,n} + \beta_2^{l,n} \exp(-\beta^n p_j^l) \quad (22)$$

with

p_j^l , average price of unit of floor-space available in zone j ;

$\beta_1^{l,n}$, $\beta_2^{l,n}$, β^n , parameters to be calibrated.

Trade coefficients of \mathbf{T} simulate the location process of tertiary and residential sectors among zones of an urban area. \mathbf{T} is obtained from two sub-matrices:

\mathbf{T}^h , sub-matrix of location probabilities (percentages) of residential sectors;

\mathbf{T}^t , sub-matrix of location probabilities (percentages) of tertiary sectors.

Of course, interzonal trade coefficients for land sectors are set to zero ($t_{ij}^l = 0$ if $i \neq j$, 1 otherwise).

As regards residential sectors, each element, t_{ij}^h , of sub-matrix \mathbf{T}^h is the probability that household segment, h , locates in zone i , conditional upon work in zone j :

$$t_{ij}^h = \text{Prob}(\text{sector } h \text{ is resident in } i \mid \text{work in } j) \quad (23)$$

According to eq. (17), eq. (23) simulates the location process of residential sectors (considered as labour production), given workplace (labour consumption) distribution across zones.

As regards tertiary sectors, each element, t_{ij}^t , of sub-matrix \mathbf{T}^t is the probability that tertiary sector, t , locates in zone i , conditional upon being consumed in j :

$$t_{ij}^t = \text{Prob}(\text{sector } t \text{ locates in } i \mid \text{consumption in zone } j) \quad (24)$$

According to eq. (17), eq. (24) simulates the location process of tertiary sector production, given the residential distribution across zones (considered as tertiary sector consumption). The location process has been simulated in the literature through entropic-gravitational or discrete choice models. Such models are formally similar, respectively, to models (18) and (19), where m indicates residential and tertiary sectors. Location systematic utility, V_{ij}^m , may be basically specified as follows (de la Barra, 1989, Echenique, 2004):

$$V_{ij}^m = p_i^m + c_{ij}^m \quad (25)$$

with

p_i^m , the selling price of sector m produced in zone i ;

c_{ij}^m , the (congested) transport cost of sector m from zone i to zone j .

More complex specifications of location systematic utility are proposed in Cascetta *et al.* (2001, 2004), including attributes such as active accessibility to public (schools, hospitals, ...) and private (shops, banks, ...) services; floor-space availability; other attributes describing the zone (security, presence of green areas,).

All considerations concerning the circular dependence specified in eqs. (19), (20) and (21) and the limited production capacity of sectors in each zone, in general, still hold. Limited production may concern restrictions in available floorspace in each zone, which could generate rent if demand for floorspace exceeds supply.

5. URBAN APPLICATION

An test application of the SETI model presented in section 3.4 is performed in the urban area of Reggio Calabria (Italy) to forecast and assess long-term changes in land use and transport patterns. The study area includes the municipality of Reggio Calabria. It consists of a central district with residential and retail activities, educational and public services clustered into three poles (university, regional government and health, municipal government); and of three suburban districts (northern, southern, hill) with manufacturing firms and scattered residences. The study area is divided into 35 zones with homogeneous socio-economic characteristics. The central district was divided into 24 zones, the northern into 6, the southern into 2 and the hill district into 3 zones.

The activity system inside the study area was segmented into 8 sectors to match available census residential and employment location data (ISTAT, 2001). Inter-dependencies between activity sectors are simulated through technical coefficients defined in a simplified Social Accounting Matrix (SAM). Coefficients connected to employment in each sector are fixed, while those connected to floorspace consumption per sector are price elastic. Travel demand, segmented into six categories (low-income work, high-income work, services, purchase, school, university), is associated to activity sectors which generate activity flows.

The current transit system comprises urban and regional bus services; regional rail services, connected with bus services through the bus terminus beside the main rail station in the central district; and inter-regional maritime services. The transit system has no direct connections among the three poles or between the latter and the rail stations, harbour and bus terminal. Trips are mainly undertaken by private mode (car), while transit services have a negligible role.

Several LUTI scenarios are defined which include facility interventions on the transit system and different land-use development configurations. Single interventions on the transit system concern frequency doubling of bus and/or railway transit lines currently operating inside the study area and the execution of a new transit system denoted with the acronym SMS (Sustainable Mobility System) (LAST, 2004). SMS is a funicular travelling in a reserved right-of-way with stops every 400-500 metres. Vehicle guidance is fully automated and the control system is centralized.

Fig. 5 shows the SMS area inside the central district: pole locations and a schematic representation of bus, rail and SMS itineraries are depicted.

Individual transport interventions may be summarised as follows:

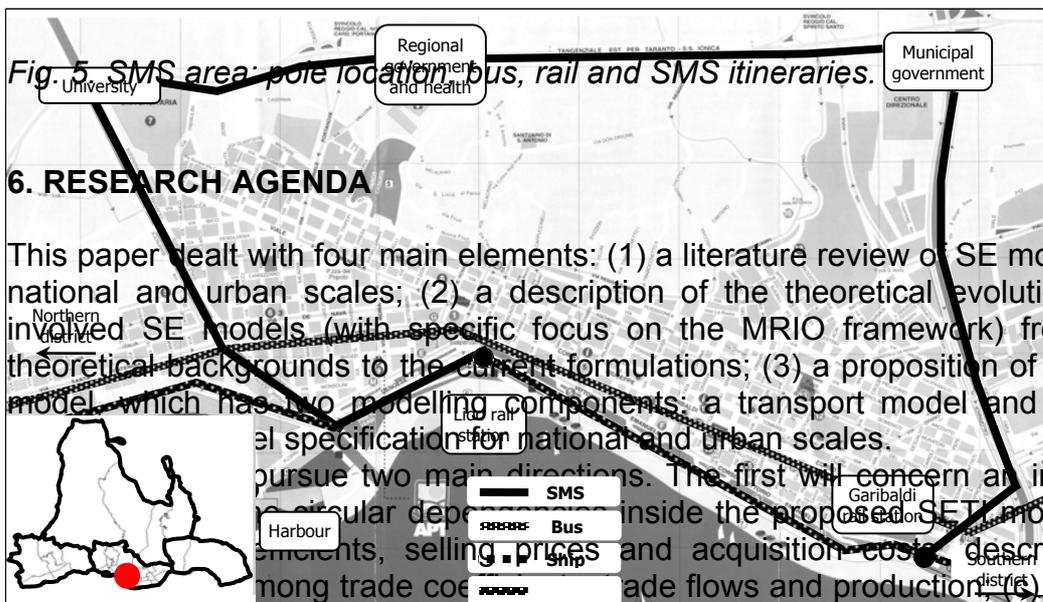
- SMS system;
- frequency doubling of bus and railway lines;

- frequency doubling of railway lines.

The land-use development configurations concern identification and different location of available land inside the study area for the settlement of new residential and economic activities:

- available land in the central district;
- available land in the southern district;
- available land in all suburban districts.
- available land in zones that have a railway station (TOD, Transit Oriented Development).

The defined scenarios require resources to implement interventions. Financial resources are estimated, allowing for annual costs of construction, maintenance and management needed for each intervention.



6. RESEARCH AGENDA

This paper dealt with four main elements: (1) a literature review of SE models at national and urban scales; (2) a description of the theoretical evolution that involved SE models (with specific focus on the MRIO framework) from the theoretical backgrounds to the current formulations; (3) a proposition of a SETI model which has two modelling components: a transport model and an SE model specification for national and urban scales.

The research will pursue two main directions. The first will concern an in-depth circular dependency analysis inside the proposed SETI model: (a) among trade coefficients, selling prices and acquisition costs; (b) among trade flows and production flows; (c) among selling prices and technical coefficients; (d) among transport costs and trade flows. The second will concern the specification, calibration and validation of the

system of demand models, which allows the estimation of freight and passenger travel demand from trade flows and transport costs.

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