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# **Multi-Regional Agent-Based Modeling of Household and Firm Location Choices with Endogenous Transport Costs**

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## **Abstract**

The paper describes a spatial economic agent-based model (ABM), consistent with the principles of new economic geography (NEG), which allows the discrete-time evolutionary simulation of complex interactions of household and firm location choices. In contrast with the current ABM approaches, it considers a multi-regional (multi-urban) setting to enable a more realistic representation of decisions related to commuting, migration and firm location. The model allows simulating spatially differentiated, multi-commodity markets for land and labor in a system of cities and the behavior of profit-maximizing firms with multi-regional asset investment decisions, incorporating endogenous transport costs with congestion effects. It also accounts for the impact of agglomeration forces on industrial location choices and the formation of urban development patterns. Other features include the representation of the actions of central and local government agents to address issues of territorial development, efficiency and equity. The conceptual framework and simulation set-up of the spatial ABM are presented and several implications are discussed with regard to the possible outcomes of a set of policy interventions.

**Keywords:** Spatial agent-based models, system of cities, location choices, traffic congestion, commuting, migration.

**JEL codes:** C63, R12, R23, R41, R53.

## 1. Introduction

Agent-based models (ABMs) are increasingly implemented in the last years to address the complex phenomena of urban agglomeration formation and development. They can microscopically represent the various forces acting upon a particular agent or actor of the system, e.g., individual, household, firm, government, at any location. In turn, they allow deriving bottom-up, discrete (step-by-step) simulation of the evolutionary path of urban processes through successive iterations. The ABM approach enables the path dependency and occurrence of outcomes which may deviate from a single steady-state equilibrium point in the prediction horizon. This deviation is due to the consideration of bounded rationality, varying degrees of intelligence and autonomy, learning capabilities and unique characteristics of myopic agents (see Tesfatsion and Judd, 2006).

In particular, spatial ABM can represent interactions among agents which take place in a spatial dimension, i.e. within a spatial entity, such as a city, with specific characteristics (size, form and connectivity), as well as spatial externalities related to economies of agglomeration, environmental pollution and congestion effects. The interactions among agents gradually alter the characteristics of the spatial entity; in turn, these alterations influence the decision-making behavior of agents. Based on the inherent advantages of this approach, the current paper describes an advanced spatial ABM framework, which incorporates the location and transport decisions and related interactions of various agents (households, firms, government) in a system of cities. Specifically, the paper aims at demonstrating a theoretically sound, integrated ABM approach, which can capture the interdependencies of all the agents' decisions within structures that are nested in time and space.

As far as the organization of the paper is concerned, Section 2 presents theoretical issues and past research efforts concerning the development of agent-based models of location choices with explicit consideration of transport costs. Section 3 explains the basic components of the model structure and interrelationships between them for a typical regional setting. Section 4 describes analytically the functions and relevant criteria associated with the decision-making behavior of each type of agent and possible linkages between them. Section 5 summarizes and concludes.

## 2. Theoretical background

There have been several spatial ABMs, which usually lack of a sound economic background, developed to demonstrate how the individual behavior of agents with bounded rationality and partial information can lead (or approximate) system-optimal equilibrium patterns, similar to analytical optimization models. Fan et al. (2000) presented a new economic geography (NEG) model with endogenous land use, labor mobility, inter-industry purchases and  $N$ -locations in one- or two-dimensional space, to underpin the development of a general equilibrium model of urban systems. Sasaki and Box (2003) showed how an optimal global spatial formation of land uses, that of von Thünen's rings, emerges from simple agents acting on local criteria, without any systematic optimization functions at the system level. Recently, Heikkila and Wang (2009) indicated how an ABM version of the Fujita and Ogawa (F-O) model of household and firm location decisions across interdependent and spatially differentiated markets for land and labor in an urban setting yields equilibrium land-use patterns which are fully comparable to those described by the analytical F -O model.

Nonetheless, existing work of ABM in NEG research is quite limited, and location choices of agents are typically restricted within cities, not across them. These ABM usually deal with the city in terms of the location of its economic and demographic activities to explain and predict the evolution of the complexity characteristics (e.g., scaling, self-similarity, far-from-equilibrium structures) of urban morphology (Fernandez et al., 2005; Crooks, 2006; Batty, 2009). More specifically, Ettema et al. (2007) developed an ABM of urban processes including farmers', authorities', investors' and developers' decisions to sell or buy land and develop it into other uses, households' residential and employment decisions in relation to life cycle events and daily activity patterns, and firms' decisions to produce and (re)locate their facilities. Devisch et al. (2009) used the ABM methodology to simulate the residential choice behavior in nonstationary urban housing markets.

Beyond the simulation of urban-scale processes, Chen et al. (2007) used an ABM to investigate the dynamic interaction between cities in a region for spatial planning and forecasting purposes. Also, McArthur et al. (2009) employed an ABM in a two-region setting to simultaneously examine commuting, migration and labor

force participation decisions and social welfare implications in the presence of road pricing.

A number of studies based on analytical economic models from the fields of urban economics and NEG have recognized the need for considering (endogenous) changes in transport costs to understand and predict the development of a system of cities. These studies have typically focused on examining why production and consumption activities are concentrated in a number of urban areas of different sizes and industrial composition rather than uniformly distributed in space (Abdel-Rahman and Anas, 2004). Traditionally, the assumption of zero transport costs (Henderson-Wilson type models) and of positive iceberg transport costs but with symmetrically located cities (Krugman type models) have been mostly adopted in current analytical economic models. In comparison to the abstract geography of those models, the NEG models allow treating cities with an explicit spatial geography. Specifically, it has been found that different transport cost and network structures can significantly affect the city size distribution and social welfare (Mun, 1997; Fukuyama and Tamura, 2003; Tabuchi et al., 2005).

In contrast with the aforementioned NEG theoretical developments, the ABM approaches mentioned before do not normally rely on dynamic spatial economic theories that can be contrasted to the observed distribution of economic activity in space (both at the urban and regional levels). Hence, they cannot provide insight into the interplay between different types of spatial friction affecting the location of economic activities between and within urban agglomerations. This interplay is also related to the facts that, on the one side, local factors may change the global organization of the economy and, on the other, global forces may affect the local organization of production and employment (Thisse, 2009). Among other things, the above interrelationship calls for a better coordination of transport policies at the urban and regional levels, through integrating different types of spatial friction.

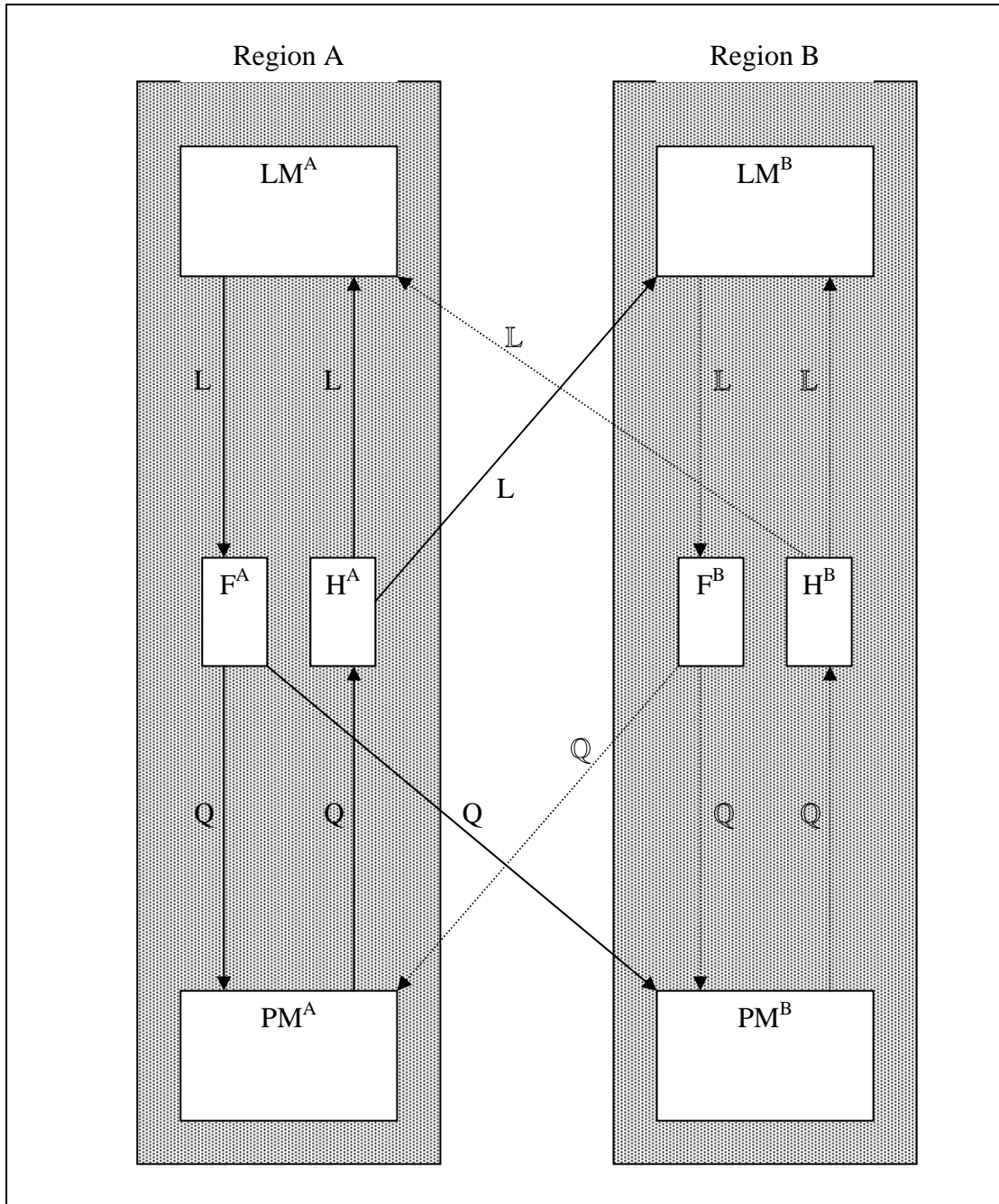
In this direction, the current paper describes a multi-city (or multi-regional) framework, recognizing the relative position of cities and their accessibility conditions, as function of the trade or transport cost. Such a framework allows identifying the main forces acting at each spatial scale from both the city and interregional viewpoints. The non-linearity relationship between the allocation (spatial distribution) of economic activity and transport cost is also recognized. For instance, a small difference in the transport cost of firms may have an asymmetrically

large impact on the spatial distribution of economic activity. The following section presents an overview of the main structural components of a multi-regional ABM of location and transport decisions.

### **3. Model Overview**

In the multi-regional ACE model of residential and industrial location there are several basic (broad) production sectors, cities (urban regions) within a wider region (or regions within a country) and types of agents, such as households, firms, municipal (or peripheral) authorities and a central government. Besides, there is explicit spatial representation of physical linkages, such as road connections, whose characteristics depend on the specific topology and network configuration. The urban (or regional) economies are linked together via interregional circular economy flows. This circular flow is illustrated in Figure 1 for the simple case of two regions (i.e., Region A and Region B). The modeling structure of such a spatial economic system can include interrelationships among some of or all the regions, depending on the overall system evolution.

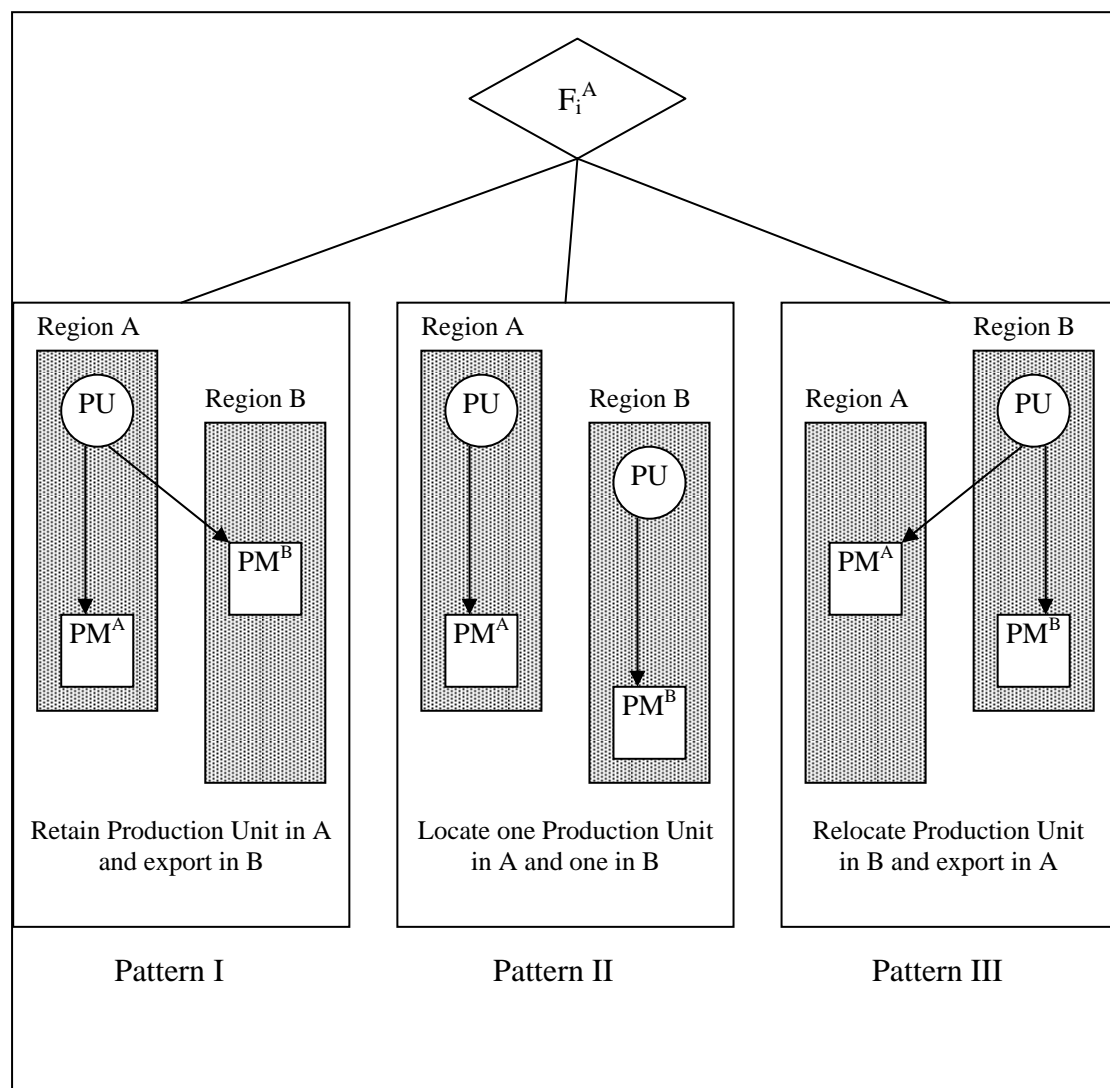
In addition to the circular economy flow within a region, there are also economy flows between the regions (A and B). First, the firms can sell products to product markets either through exporting to another region or by local production in both regions. Second, the households can work in a region other than their residential region, through traveling daily from residence to work place. Hence, some of the households will supply labor to the other's region labor market and some others will supply labor to the local (residential) labor market. It is assumed that each specific household agent can supply labor to only one labor market, which, in this example, is denoted as  $LM^A$  for Region A or  $LM^B$  for Region B. In particular, the possible kinds or patterns of interregional linkages among the regions for firms and households (product and labor markets) are depicted in Figures 2 and 3, respectively.



**Figure 1: Circular economy flow and interregional relationships illustrated for the case of two regions**

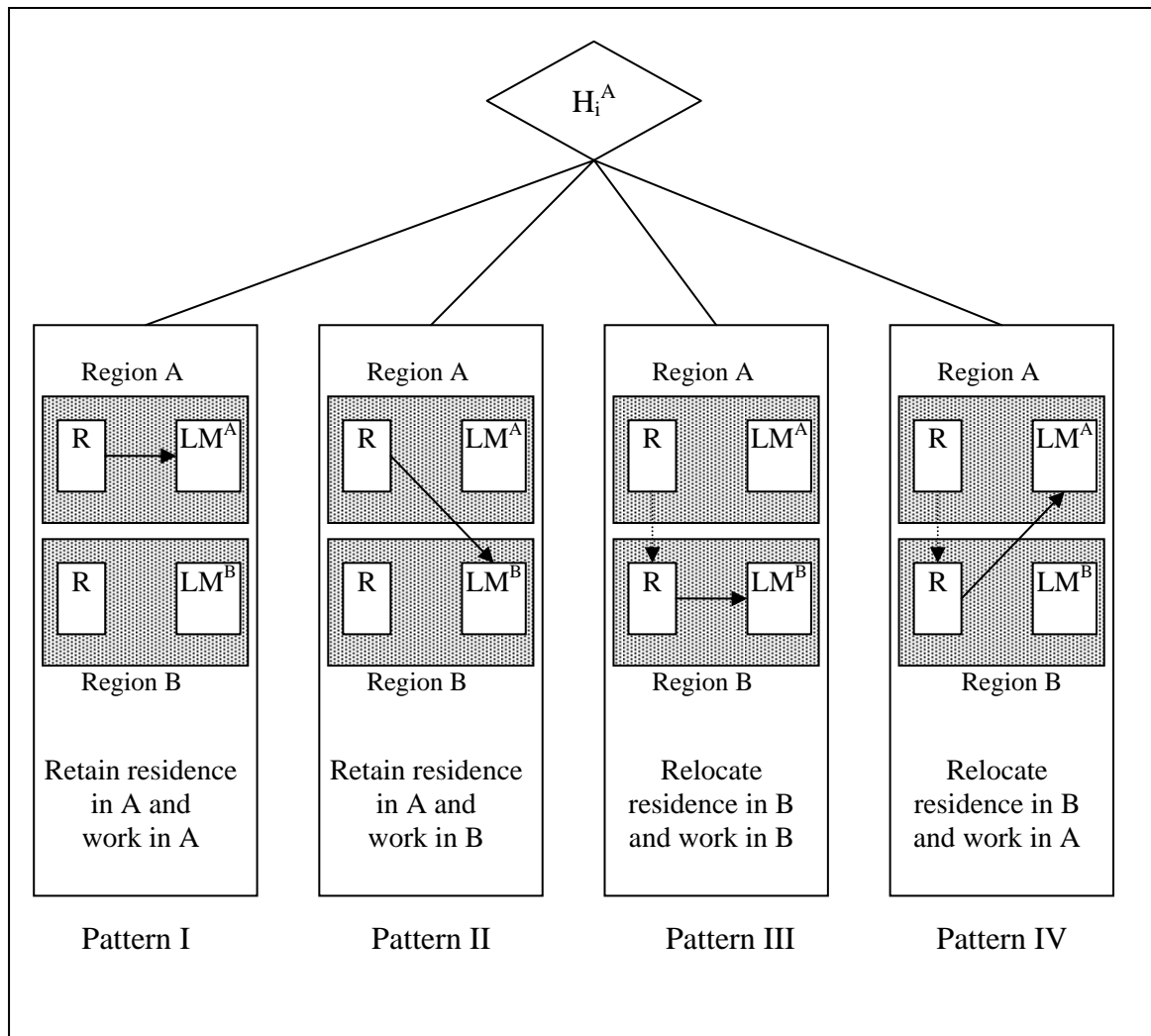
Turning first to the firms, Figure 2 illustrates the possible location choices and patterns of production and products distribution for firms between two regions, which also determine the patterns of interregional linkages. Location choice or pattern I involves the local supply of goods to the local product market and the exporting of goods to the other product market, which involves a transport cost of shipping the goods from one region to the other. Pattern II refers to the situation where both product markets are supplied locally through the firm's production units located in

both regions. In this case, the firm's choice is the construction of a new production unit (direct investment) in the other region instead of exporting. Finally, a third choice (pattern III) is the relocation of the firm's production unit to the other region and, thus, the firm supplies goods locally to the product market of region B and exports to A. Given the existence of transport costs and that production-related aspects, such as land costs, labor and input costs and agglomeration economies, and market-related considerations, such as market size and demand conditions, may differ considerably between regions, all the above patterns represent possible and rational choices for any given firm.



**Figure 2: Firm location choices and three possible patterns of product distribution illustrated for the case of two regions for firms initially located in region A**

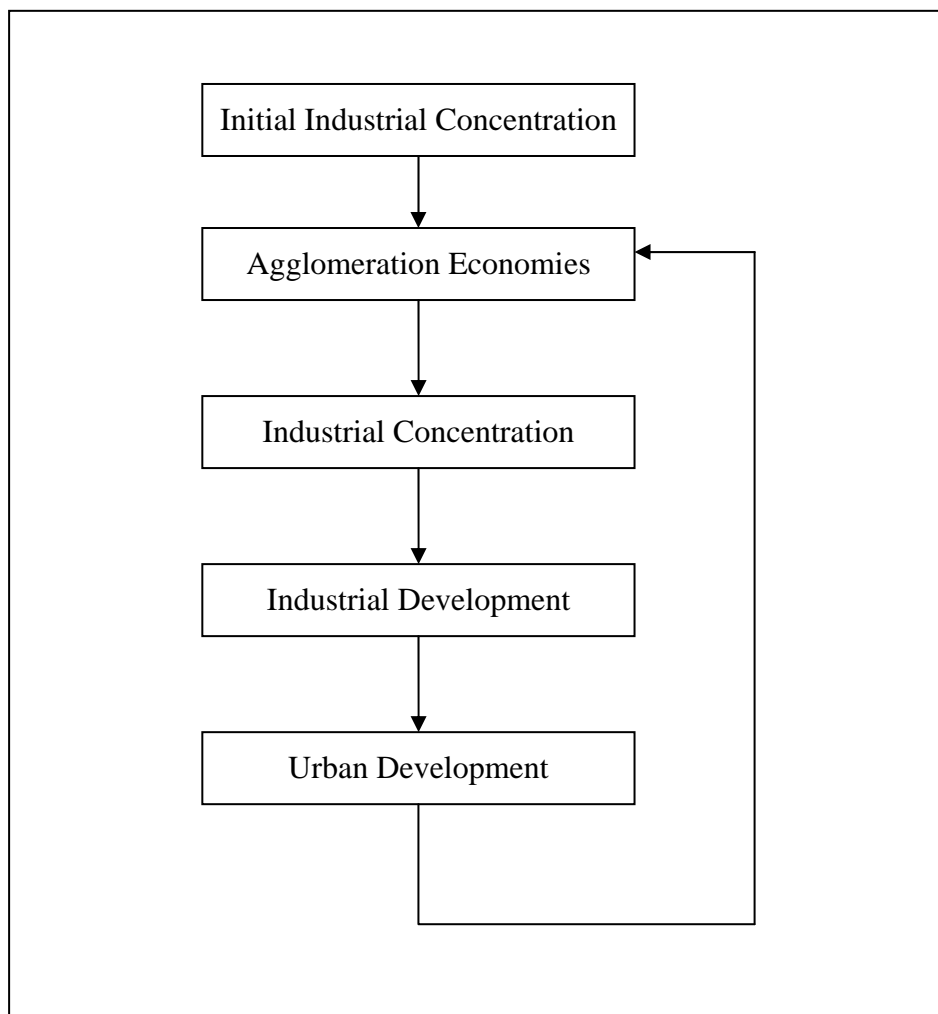




**Figure 3: Household choices of residence and employment region with four possible patterns illustrated for the case of two regions for households with initial residence in region A**

Regarding the households, we allow for four possible choices, as presented in Figure 3. First, the household agent can simply live (reside) and work in the initial urban region. Second, the household can choose to live in the initial region of origin and work in some other region. The latter choice involves daily traveling between the regions and a related commuting cost for the agent. A third possible choice is to migrate to some other region and work there. This choice involves relocation of residence as well as work place. Finally, the household's fourth choice is to migrate to some other region (relocating its residence) and work in its initial region of origin. All these choices are rational ones, since various conditions may differ among regions such as housing cost, living costs (prices of goods), wage and local taxes.

The objective of the firm and household agents is to maximize their profits and utility, respectively. In order to achieve it, they should make the appropriate location choices, as illustrated in the patterns of Figures 2 and 3 and discussed before. Since various local conditions (or factors) in each region may endogenously change and differ (arguably, increasingly diverge) over time, the agents have to regularly update/adjust those location choices. The adjustment of location choices is carried out by comparing all relevant factors and parameters in all regions. The spatial behavioral responses of agents to the changing local and global conditions can be expressed with specific moves which can maximize their objective (profit or utility) function. The current modeling structure can represent the interplay between the local and global factors of the spatial economy and transport system, through a series of movements of the agents (households and firms) within each region and between regions.



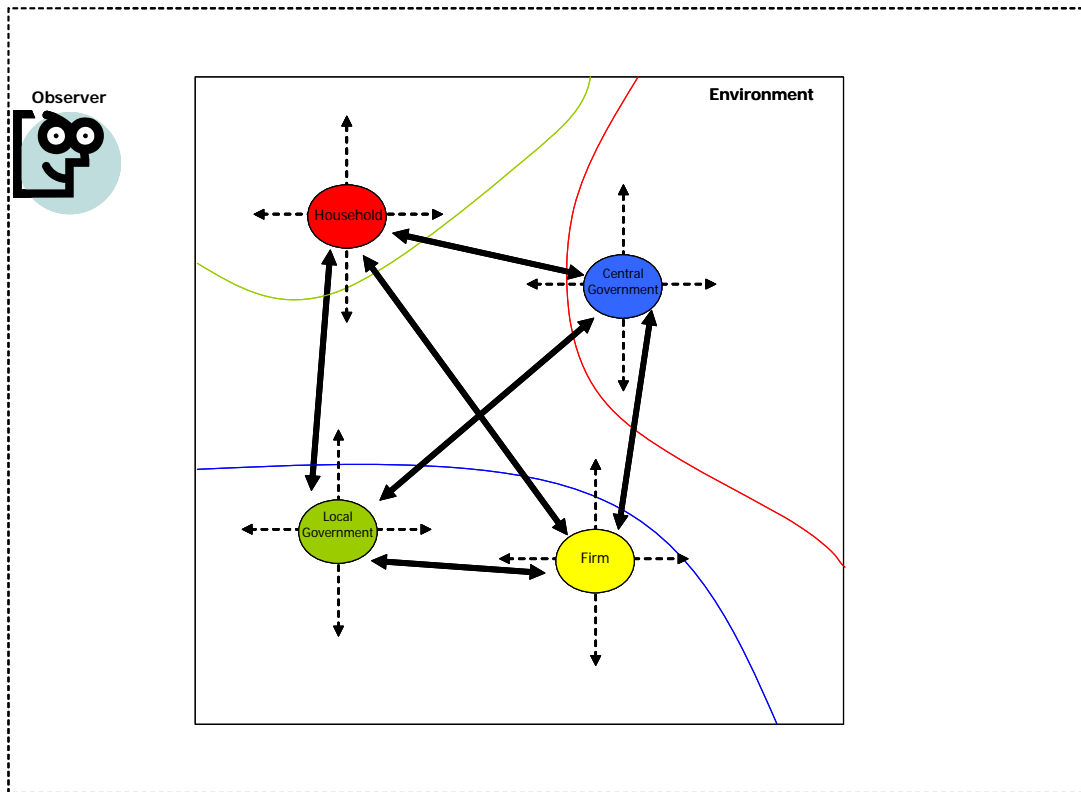
**Figure 4: Cumulative circular causation of industrial and urban agglomeration**

Furthermore, the structure of this model explicitly represents the formation and development effects of sector-specific agglomeration economies. Though there may be several local factors affecting the spatial system dynamics without being related to agglomeration forces, a core-periphery scenario depending on the specific conditions constitutes a possible pattern of evolution. More specifically, it is here assumed that an initial industrial concentration within a region may induce a self-reinforcing industrial and urban agglomeration process. Figure 4 shows the sequential steps and circular causation involved in the development of industrial and urban agglomeration economies.

Finally, the changing feedback dynamics between transport cost and spatial allocation of economic activities may call for some political intervention of the central/federal government, in order to ensure a degree of equity (spatial balance or fairness) between the regions. In this case, the local governments of urban regions, acting either competitively or complementary to each other, will use policy instruments (e.g., tax incentives) to increase efficiency (attract more firms to grow revenues from taxes), while central government will employ such instruments as taxes and (infrastructure) investments to foster an efficient as well as balanced scheme for the evolution of the system of cities.

#### **4. Agents, Location Choices and Spatial Markets**

This section presents the various types of agents involved in the simulation model setup and the behavioural attributes underlying the decision-making process of each agent. These agents include households, firms, central and local government. Figure 5 illustrates the different types of agents and the interactions between them in the simulation environment. All agents are allowed to influence the decisions of each other. These interactions may involve cross-feedback relationships in multiple time (days, months, years) and spatial (neighbourhood, city, region) scales.



**Figure 5: Illustration of different types of agents and interactions between them**

#### **4.1 Household agents**

The household location choice behavior can be generally expressed as a function  $H$  of the following factors:

$$H = \{\text{Net wage, housing cost, transport cost, adjustment cost}\},$$

A von Thünen linear urban model is adopted according to which the residential and industrial areas are spatially arranged in concentric zones around the city centre. The location choice behavior is subject to utility-maximizing behavior of households. Let the utility  $U$  be expressed as:

$$U = \{X_1, X_2, X_3\} = X_1^a X_2^b X_3^c \quad (1)$$

with  $a + b + c = 1$ ,

where  $X$  is the quantity to be consumed from a particular commodity group, and  $a$ ,  $b$  and  $c$  denote the contribution of each commodity group to the household utility measure. It is noted that other functional forms of the utility function can be alternatively included in the model without loss of generality. The quantity  $X$  can be expressed as a function of the total disposable household budget  $B$  and the average consumer price  $p$  of each commodity group. Then, the utility-maximizing behavior of a household whose head is occupied at production sector  $m = 1, 2, 3, 4$  with housing location  $i$  at a given time period can be expressed as:

$$\max U = \left( \frac{\alpha B}{p_1} \right)^a \left( \frac{\beta B}{p_2} \right)^b \left( \frac{\gamma B}{p_3} \right)^c, \quad (2)$$

subject to  $\alpha + \beta + \gamma = 1$ ,

where  $\alpha$ ,  $\beta$  and  $\gamma$  denote the corresponding consumption budget shares. The households can differ with respect to the above parameters. This means that they may have a different income-budget distribution spent on the four commodity groups.

In addition, the individual preferences for a given commodity group as well as a given variety within this commodity group (produced by a given firm) may also differ according to the household's demand function relating the quantity demanded  $Q$  to each firm's variety and price:

$$Q_{i,j}^d = f(P_j) = \kappa(v, t) + \lambda P_j, \quad (3)$$

where the index  $i$  denotes households and  $j$  firms, and  $\kappa, \lambda$  are parameters. The households have a variety parameter ( $v$ ), which determines the number of varieties that they prefer, and assign a preference-tastes index ( $t$ ) for each variety produced by a firm. This index demonstrates which firms they prefer and from which firms choose to buy in order of priority (this can be a random assignment). The household's total demand function for a given commodity group is the sum of the demand functions of each variety that the household prefers. An equal amount of income is spent on the

varieties; namely, the variety budget shares are equal to  $1/v$  (an alternative weighting scheme among the varieties may be well applied).

Then, the location choice function of a household agent  $h$  with housing location  $i$  and employment location  $j$  can be specified as follows (here, the time period and production sector indices are omitted from model specification for brevity purposes):

$$H_{i,j} = (1 - \tau_h)W - \left( \frac{\eta_h N_h}{H_h} \right) \left( r_0^h + \frac{R_h}{2} g_0^h \right) - C_{ij}^* - \frac{g_0^h d_{ij}}{s} \quad (4)$$

where  $\tau_h$  is the labor (wage) tax, and the wage  $W = \frac{wL}{N_L}$ , with  $w$  being the wage rate,

$L$  the total labor (in monetary terms) and  $N_L$  the number of labor agents (firm size).

The second term of equation (4) expresses the residential land cost:  $\eta_h$  is the available lot size per household,  $N_h$  is the total number of household agents,  $H_h$  is the total available land for households,  $r_0^h$  is the reference housing rent value,  $R_h$  is the radius of the urban residential area and  $g_0^h$  is the average private vehicle motoring cost (in monetary terms) (Euros per kilometre).

The third term relates to the commuting cost:  $C_{ij}^*$  is the optimal travel cost between a city (or urban zone) pair  $i - j$  accounting for congestion effects and possible road (congestion) toll rates. The value of  $C_{ij}^*$  can be determined with the application of a stochastic user-equilibrium (SUE) traffic assignment model. Based on the SUE model, no traveler could decrease the perceived travel cost by unilaterally changing the route between  $i - j$  (Daganzo and Sheffi, 1977). The latter model allows representing variations in the perceived generalized travel cost and uncertainty in the route choice behavior of the agents using the (road) transport network. However, it does not explicitly account for the individual heterogeneity in decision rules. In contrast with the SUE concept, Zhang et al. (2008) suggested the behavioral user equilibrium concept within an ABM framework, wherein equilibrium in route choices is achieved if no traveler has incentives to change route, given the information available and value of time.

The mobility utility function of each agent can be expressed as:

$$U_{ijk} = -\theta C_{ijk} + \varepsilon_{ijk}, \quad (5)$$

where  $U_{ijk}$  expresses the utility of agent selecting path  $k$  for moving between  $i-j$  pair,  $\theta$  is the path cost perception parameter and  $\varepsilon_{ijk}$  is a random error term, independent and identically distributed for all routes. In the case where a Gumbel distribution is assumed for the error term, a logit route choice model is then obtained, which provides the probability  $\Pi_k$  of selecting a path  $k$  between  $i-j$  pair:

$$\Pi_k = \frac{\exp(C_{ijk})}{\sum_k \exp(C_{ijk})}, \quad (6)$$

The path travel cost  $C_{ijk}$  is expressed in monetary terms, as a composite function of the value (VOTT) of travel time  $t$  along the links  $a \in k$  and the toll charge  $p_a$  incurred by the users of those links, as follows:

$$C_{ijk} = \sum_{a \in k} \delta_{a,ijk} [\text{VOTT } t(x_a) + p_a], \quad (7)$$

where  $\delta_{a,ijk}$  are the elements of the link-path incidence matrix. These elements are binary parameters taking the value 1, if link  $a$  is part of the path  $k$  between  $i-j$  pair, or 0 otherwise. The link-path incidence matrix is derived through the network loading procedure of the logit-based SUE assignment of the trip demand so that yield the lowest total travel cost. The variable  $x_a$  denotes the traffic flow at link  $a$  and is expressed as a composite measure obtained from the weighted (based on equivalent passenger vehicles) summation of all households' car and firms' truck volumes using the inter-city network per unit of time period. The estimation of the inter-city transport demand responses of agents to changes in path travel cost is based on the following relationship:

$$D_{ij}^{\tau} = D_{ij}^{\tau-1} \exp(uC_{ij}), \quad \forall i, j, \quad (8)$$

where  $D_{ij}^{\tau}$  and  $D_{ij}^{\tau-1}$  refers to the level of transport demand of agents moving between  $i - j$  pair during the current  $\tau$  and past  $\tau - 1$  time period and  $u$  is a scale parameter, which may vary with the characteristics of each agent. In order to calculate the travel time  $t_a$  at link  $a$ , the Bureau of Public Roads (BPR) function can be used:

$$t_a(x_a) = t_a^0 \left( 1 + \mu \left( \frac{x_a}{G_a} \right)^{\beta} \right), \quad (9)$$

where  $t_a^0$  is the link travel time at free-flow conditions,  $\mu$  and  $\beta$  are parameters referring to local operating conditions (typically,  $\mu = 0.15$  and  $\beta = 4$ ) and  $G_a$  is the maximum traffic capacity at link  $a$ . The capacity may be allowed to change over time (expanding roads) through central government financing either by a head tax or by a congestion toll ( $p_a$ ). If financed by a toll, the excess (or shortfall) in toll revenue can then be redistributed among the households' and firms' agents of each region (Anas and Xu, 1999). The fourth term of equation (4) corresponds to the adjustment costs:  $s \in (0, 1)$  denotes the speed of adjustment and  $d_{ij}$  is the network distance between pair  $i - j$ .

Several ABM have been recently developed to facilitate the representation of interactions among network owners/operators, individual users and congestion dynamics in the presence of road pricing and other transport costs (Bazzan and Junges, 2006; Markose et al., 2007; Holguín-Veras, 2008; Takama and Preston, 2008; Gourley and Johnson, 2009; Liedtke, 2009; Roorda et al., 2010). In particular, Zhang et al. (2008) used an agent-based travel demand model wherein each traveler has learning capabilities and unique characteristics, and demonstrated the crucial role of user heterogeneity in the estimation of the welfare consequences of toll and capacity choices in congested transport networks under different ownership structures.

#### **4.2 Production sectors**

The model assumes a four-sector classification of the economy and corresponding commodity groups produced by these sectors. These sectors include:



- (a) Agricultural food sector,
- (b) Intermediate goods sector,
- (c) Manufacturing sector,
- (d) High-technology sector.

The above sectors differ from each other with respect to the labor and capital intensiveness, level of labor skills and returns to scale. The intermediate goods sector produces only intermediate inputs to be used by firms of the manufacturing and high-technology sectors and no final goods for consumption by the households. The other three sectors produce final goods.

### 4.3 Firm agents

The location choice behavior of firms can be generally expressed as a function  $F$  of the following factors:

$$F = \left\{ \begin{array}{l} \text{Firm profit, taxation, labor cost, land, capital and distribution cost,} \\ \text{productive public capital stock, agglomeration economies of each sector} \end{array} \right\}$$

The firm's cost of distributing its products from urban region  $i$  into other urban regions  $j$  can be included in the price of intermediate goods and is represented by the measure of travel cost  $C_{ij}^*$  between  $i-j$ , as described in the subsection 4.3. The location choice for the production and product distribution pattern of each firm agent is subject to profit-maximizing behaviour. A Constant Elasticity of Substitution (CES) production function is assumed of the following general form:

$$q = f(K, L, M) = \left[ \alpha K^{-\rho} + \beta L^{-\rho} + \gamma M^{-\rho} \right]^{\frac{\nu}{\rho}} \quad (10)$$

with  $\alpha + \beta + \gamma = 1$ , where  $q$  denotes output, and  $K$ ,  $L$ , and  $M$  stand for the production factors of capital, labor, and intermediate inputs, respectively. The parameter  $\nu$  is a measure regarding the returns to scale, whilst  $\rho$  yields the elasticity of substitution  $\sigma$  between production inputs, as follows:

$$\sigma = \frac{1}{1 + \rho} \quad (11)$$

The capital is assumed to be owned by the firms and purchase the services of the other factors. For firms belonging to the agricultural food sector as well as the intermediate goods sector, the production function reduces to only two factor inputs:  $K$  and  $L$ . Manufacturing and high-technology firms use all the three production factors. Additionally, within each production sector individual firms may differ in their production efficiency. This difference reflects to parameter values of the respective production functions.

#### ***4.4 Product and labor markets***

Firms are assumed to operate in imperfect competitive markets. The total demand function for a firm's product in a region is the sum of the individual household demand functions of the product. The price is determined according to the downward-sloping demand function that the firm faces at the profit-maximizing output level for each particular region, i.e., at the intersection of marginal revenue ( $MR$ ) with marginal cost ( $MC$ ), so that  $MR=MC$ . The wage in each region is determined by the labor market, i.e., the demand and supply of labor, which is assumed to be competitive. Each household supplies a given amount of labor units (e.g. hours per day etc). The total labor supply in the region is the sum of those labor units. The total demand for labor in each region is the sum of the labor demand of each firm in the region.

#### ***4.5 Agglomeration economies***

The modeling of the formation and development of the system of cities assumes the existence of sector-specific agglomeration economies, in the form of localization economies. The agglomeration economies are external productivity benefits to the firms. In general, if the production function of a firm is given by:

$$q = f(K, L, M),$$

where the notation of the general production function is the same as in equation (10), then, in the presence of agglomeration economies the production function becomes:

$$q^* = g(Q, D) \cdot f(K, L, M), \quad (12)$$

where  $g(Q, D)$  is the agglomeration function, which has a shifting productivity effect to the firm's production function. Agglomeration economies are expressed here as a function of the total output level ( $Q$ ) of a specific sector in a given region and of the region's firm density of a specific sector ( $D$ ). Total regional output in a given sector is the sum of the output of all firms ( $n$ ) in the region belonging to that sector without initially the agglomeration effect:

$$Q = \sum_{i=1}^n q_i \quad (13)$$

In particular, the function of agglomeration economies takes the following form:

$$g(Q, D) = \frac{\alpha Q^3}{\exp\left[\beta \frac{Q}{D}\right] - 1} \quad (14)$$

For appropriate parameter values, function (14) produces a sigmoid shape that reflects the assumption that the stronger the agglomeration economies (external productivity benefits) are, the stronger the industrial concentration (as measured by the sector's total output,  $Q$ ) and the firm density ( $D$ ) become. However, it also reflects the assumption of congestion costs and de-agglomeration economies at high levels of agglomeration, resulting in weaker marginal agglomeration economies.

#### ***4.6 Central and local government agents***

In the current ABM framework, there exist two layers of government, which themselves are agents, as in a fiscal federalism structure. The central or federal government is concerned with the welfare level of the whole economy. It has several policy variables available, such as taxation on households' income, corporate income,

Value Added Tax (VAT) and country-wide public investment. This public investment includes capacity provision to the (road) transport network interconnecting the system of cities. As mentioned in Section 3, all these variables can be suitably employed to improve the total system welfare level, which can be generally expressed as a weighted function of the aggregate system efficiency and territorial equity among regions.

Each urban region has a local government, which is concerned only with its own regional welfare level. It has the same tax policy tools available as the central government and, hence, there is a tax-base sharing, creating potential vertical fiscal externalities. Since each local government sets its own tax rates, there are also spatial fiscal interaction effects among local jurisdictions, which create horizontal fiscal externalities. These externalities can be positive (benefit spillovers) and related to networks effects and synergies between regions, or negative due to taxation and/or investment competition among each other. The local governments also provide a local public good, which is consumed and has effects only locally within each jurisdiction. De Borger and Proost (2004) discussed the fiscal externalities arising when the pricing or expenditure policy in the transport sector of one government affects the policy of other governments by producing congestion and environmental externalities. A comprehensive analysis of possible fiscal interaction effects between systems of regions is provided in (Ahmad and Brosio, 2006).

## **5. Summary and Conclusions**

This paper described the conceptual framework and structure of an integrated agent-based model for location and transport decisions in a multi-regional or city system setting. The study is motivated by the increasing complexity of commuting and migration patterns at regional level, current advances in agent-based technology and the need for strengthening the theoretical underpinning of current spatial ABM of location and transport decisions in the context of the NEG. The model encompasses temporal and geographical interdependencies of households', firms' and governments' decisions on the spatial allocation of economic activities and use of transport infrastructure. The transport cost is incorporated in both the location choice functions of households (for commuting) and firms (for distributing their goods), as well as the investment decisions of central government to enhance the total system

welfare level. Thus, it is endogenously taken into account when household (or firm) agents consider the tradeoff between migration (relocation) and commuting (distribution) cost. Local government investments (e.g., on public transport and Intelligent Transport Systems) could also be regarded to reduce urban congestion and improve intra-urban commuting and distribution costs. Future research efforts will focus on the experimental evolutionary analysis and real-world implementation of the proposed ABM framework for different types of systems of cities and policy scenarios.

## 6. References

Abdel-Rahman, H. and Anas, A. (2004) Theories of systems of cities. In: *Handbook of Regional and Urban Economics*, Henderson, J.V. and Thisse, J-F (eds), Vol. 4, Chapter 52, Elsevier, Amsterdam, 2293-2336.

Ahmad, E., and Brosio, G. (eds.) (2006) *Handbook of Fiscal Federalism*, Edward Elgar, New York.

Anas, A., and Xu, R. (1999) Congestion, land use, and job dispersion: A general equilibrium model, *Journal of Urban Economics*, 45 (3), 451-473.

Batty, M. (2009) Cities as complex systems. Scaling, interactions, networks, dynamics and urban morphologies, *Encyclopedia of Complexity and Systems Science*, Part 3, Meyers, R.A. (ed.), Springer, New York, 1041-1071.

Bazzan, A.L.C., Junges, R. (2006) Traffic network equilibrium using congestion tolls: a case study. *Proceedings of the 4th Workshop on Agents in Traffic and Transportation*, Bazzan, A.L.C., Chaib Draa, B., Kluegl, F. and Ossowski, S. (eds.), ACM, New York, NY, 1-8.

Chen, H-X., Xi, B., Zou, H-M., Li, G-P., and Huang, Q-G. (2007) Multi-agent based regional spatial structure evolution simulation for forecast and plan, *Proceedings of the Sixth International Conference on Machine Learning and Cybernetics*, Hong Kong, 19-22.

Crooks, A.T. (2006) Exploring cities using agent-based models and GIS, *Proceedings of the Agent 2006 Conference on Social Agents: Results and Prospects*, University of Chicago and Argonne National Laboratory, Chicago, IL.

Daganzo, C.F., and Sheffi, Y. (1977) On stochastic models of traffic assignment, *Transportation Science*, 11(3), 253–274.

De Borger, B., and Proost, S. (2004) Vertical and horizontal tax competition in the transport sector. *Reflcts et perspectives de la vie économique*, 43 (4), 45-64.

Devisch, O.T.J., Timmermans, H.J. P., Arentze, T.A., and Borgers, A.W.J. (2009) An agent-based model of residential choice dynamics in nonstationary housing markets, *Environment and Planning A*, 41(8), 1997–2013.

Ettema, D., de Jong, K., Timmermans, H., and Bakema, A. (2007) Puma: Multi-agent modelling of urban systems, In: *Modelling Land-Use Change Progress and Applications*, Koomen, E., Stillwell, J., Bakema, A., and Scholten, H.J. (eds), Springer Netherlands, 237-258.

Fan, W., Treyz, F., and Treyz, G. (2000) An evolutionary new economic geography model, *Journal of Regional Science*, 40 (4), 671-695.

Fernandez, L.E., Brown, D.G., Marans, R.W. and Nassauer, J.I. (2005) Characterizing location preferences in an exurban population: implications for agent-based modeling, *Environment and Planning B*, 32 (6), 799–820.

Fukuyama, K., and Tamura, M. (2003) Consolidation of network infrastructure by competitive local governments, IEEE International Conference on Systems, Man and Cybernetics, Vol. 5, 4407-4412.

Gourley, S., and Johnson, N.F. (2009) Effects of decision-making on the transport costs across complex networks, *Physica A*, 363 (1), 82-88.

Heikkila, E.J., and Wang, Y. (2009) Fujita and Ogawa revisited: an agent-based modeling approach, *Environment and Planning B*, 36 (4), 741-756.

Holguín-Veras, J. (2008) Necessary conditions for off-hour deliveries and the effectiveness of urban freight road pricing and alternative financial policies in competitive markets, *Transportation Research Part A*, 42 (2), 392-413.

Liedtke, G. (2009) Principles of micro-behavior commodity transport modeling, *Transportation Research Part E*, 45 (5), 795-809.

Markose, S., Alentorn, A., Koesrindartoto, D., Allen, P., Blythe, P., and Grosso, S. (2007) A smart market for passenger road transport (SMPRT) congestion: An application of computational mechanism design, *Journal of Economic Dynamics and Control*, 31 (6), 2001-2032.

McArthur, D.P., Thorsen, I., and Ubøe, J. (2009) Congested interregional infrastructure, road pricing and regional labour markets, Discussion Papers, 2009/3, Department of Finance and Management Science, Norwegian School of Economics and Business Administration, Bergen, Norway.

Mun, S.-i., (1997) Transport network and system of cities, *Journal of Urban Economics*, 42 (2), 205-221.

Roorda, M.J., Cavalcante, R., McCabe, S., and Kwan, H. (2010) A conceptual framework for agent-based modelling of logistics services, *Transportation Research Part E*, 46 (1), 18-31.

Sasaki, Y., and Box, P. (2003) Agent-based verification of von Thünen's location theory, *Journal of Artificial Societies and Social Simulation*, 6 (2), 172-189.

Tabuchi, T., Thisse, J.-F., and Zeng, D.Z. (2005) On the number and size of cities, *Journal of Economic Geography*, 5 (4), 423-448.

Takama, T., and Preston, J. (2008) Forecasting the effects of road user charge by stochastic agent-based modeling, *Transportation Research Part A*, 42 (4), 738-749.

Tesfatsion, L., and Judd, K.L. (eds) (2006) *Handbook of Computational Economics. Vol. 2: Agent-Based Computational Economics*, Elsevier/North Holland, Amsterdam.

Thisse, J-F (2009) Toward a unified theory of economic geography and urban economics, *Proceedings of the Journal of Regional Science 50th Anniversary Conference: "Regional Science: The Next Fifty Years"*, Federal Reserve Bank of New York, N.Y.

Zhang, L., Levinson, D., Zhu, S. (2008) Agent-based model of price competition, capacity choice, and product differentiation on congested networks, *Journal of Transport Economics and Policy*, 42 (3), 435-461.