TOWARDS AN AGENT-BASED MODEL OF EURO COINS' DIFFUSION

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ABSTRACT
This article is expected to provide an improved methodology for the construction of a macro-meso-micro European mobility model within a multidisciplinary framework. Such a research is supposed to lead to a better understanding of the spatial and social structure of the relations between European countries and citizens that we grasp by studying the diffusion of foreign Euro coins. An Agent-Based Model prototype is developed in this sense to bring to light multiple components of diffusion acting on different spaces and temporalities. Assumptions on macroscopic mobility are taken into account by spatial interaction models and agent-based models, with sociological parameters of individual behavior being mostly related to the social network analysis and the time geography in order to model mobility decisions (scheduling of activities and destination choices).

KEYWORDS
Agent-Based Modeling, spatial interaction, coins transactions, multilevel, international mobility

1. INTRODUCTION

1.1 General Objective

The general objective of the author PhD thesis is to reveal the spatial and social structures of the relationships between European countries and citizens from Euro coins dissemination processes. A substantial part of our research is based on the analysis of aggregated patterns of coins diffusion throughout European countries using the ESDO (Euro Spatial Diffusion Observatory) database. Those aggregated patterns however result from multiple interactions between individuals through time and space. The very essence of coins diffusion is indeed a monetary transaction between two people sharing the same coin machine or the same cash drawer in a short period of time. It is a fairly simple process but repetitions and the mobility of people lead to complex structures over space. Such a process leans itself into diffusion and spatial interaction theories (Wilson, 2002). In this particular paper however, it is argued that Agent-Based Model (ABM) can help in revealing how aggregated patterns emerge over time from individual monetary interactions. In recent years, spatial ABM's have demonstrated their capacity to help in identifying the source of complex spatial patterns (e.g. Parker (2007) and Banos (2010)).

In this paper we sketch-up an ABM prototype that simulates coins exchange in a simplified space. It is assumed that coins movements act at multiple levels and that they have a stochastic component. Moreover, the model embeds the mobilities and exchange processes portrayed from empirical analysis by Grasland and Guérin-Pace (2003) and Nuno et al. (2005). In fact, as a Euro coin is conveyed across space by persons, it offers a good representation of both social and spatial networks, as well as it allows the study of both territorial inequalities with regards to international accessibility and social inequalities, when looking at international contacts. Behind those questions lurk important issues both in terms of planning (identifying places that are most open to international and are forming peaks of potential innovation) and political construction of the EU. What are the social categories that are the most connected to neighboring peoples and which are therefore potential vectors for establishing a common European identity? What places / people are the most likely to be points of entry or points of international dissemination of an epidemic affecting European territory?

The main purpose of this paper is to build up a theoretical simulation model on simplified space to reveal patterns of diffusion in an international settlement system. More precisely, the paper aims at investigating the flows and movements of persons within the network of cities in Europe. This article attempts to answer the methodological question of measuring the intensity of social and spatial networks that are established on both sides of borders in Europe, since the introduction of the common currency on 1 January 2002. As money is largely spatially redistributed by individuals, examining the distribution of euro coins seems to be an original way to access and measure the importance of relationships between people located in different European countries and to determine the degree of integration of regions and cities within the regional neighborhood (Berroir et al., 2005). Indeed, as objects carried by individuals, a significant amount of foreign coins concentrated in one point is considered to be a reflection of the existence of multiple paths between the concerned place and the rest of the Eurozone. It is by then considered an indirect territorial marker of international openness, when that kind of data is currently missing (Grasland and Guérin-Pace, 2003, 2004).

1.2 A conception at the disciplinary crossroads

If money circulation has been mainly described as a random walk - Brownian movement (Blokland et al., 2002; Stoyan, 2002; Stoyan et al., 2004 in their prior work on euro coins circulation) and Lévy flights (Brockmann and Theis, 2008; Brockmann, 2010), we argue that, as money doesn't move by itself, only destination's choices of the individuals matter.

Considering the individual in its decision leads us to the decision trees used in disaggregated land use and transport models since travel demand is derived from the demand for activities (Bowman, 1998; Ben-Akiva and Bowman, 1998), meaning that travel is not only constrained by space but also by time (Hägerstrand, 1970). All these assumptions are summarized in Roy (2004:5), explaining that: "travel is a demand derived from the need to carry out activities at various times at other points in space". In the model, the rules constraining the mobility of the agents transporting the coins are based on previous methodologies which are linked to mobility decisions and spatial interaction models, implemented here within the frame of a probabilistic simulation of discrete destination choices.

Thill and Thomas (1987) claim that theoretical studies of trip-chaining behavior were developed mainly in connection with central place theory and the previous standard formulation of consumer demand in space by Lösch(1940). If new geographical economics has made criticisms about the old models in location theory, and thus on the prior works of Christaller (1933) and Lösch (1940), it has nevertheless be considered that they are still relevant when it comes to modeling the evolution of urban systems (Fujita and Krugman, 2004) (p.147). As the interest of the model is not market areas but cities' locations, a Löschian environment appears to be a relevant way to differentiate spaces through cities' size and location.

2. MODEL

The objective pursued here is to model a certain number of exchanges and coins brewing within a fictive isolated continent made from people living in cities located in different countries. The model will be split into five components: the environment, the money, the agents, the timeline and activity scheduling, the destination choice and finally the exchange of coins.

2.1 Environment

Following Christaller (1933) and Lösch (1940), the environment of the model has been built using a network of cities, hierarchically defined according to three different administrative levels and localized within three different countries. To fit as much as possible with the European Union geography (Cattan et al., 1994; Cicille and Rozenblat, 2003), the will was to find a standard exogenous situation in which the cities system would follow a well-defined hierarchical structure.

The structure follows an administrative principle (i.e. the scale parameter k is equal to 7) in order to prevent cities to be located on borders (which would have implied that they would share a common population and that money in cities from the beginning of the model could have had different origins) and to keep the exact same internal structure in the different countries. The total system is thus made of 3 large, 18 middle-sized and 90 small cities.

As the objective is similar to the transportation network inherent to the minisum location problem (Ottaviano and Thisse, 2005), the network of cities is assumed to be as close as possible to a planar straight-line graph. Hence, it has been built following a Delaunay triangulation (i.e. the sum of vertices from origin *i* to destination node j is minimal and within the network, every city can be either an origin *i* and a destination *j*).

Moreover, as tourism is a great source of international mobility and thus of inequality within territories, two touristic landscapes (sea and mountain) have been added to the environment. According to Christaller (1933), touristic sites are located in peripheral areas, which is the reason why they have been localized at the external borders of the continent. In order to be able to distinguish the influence of such migrations on the local brewing of coins, we have kept a country free of these particular external amenities.

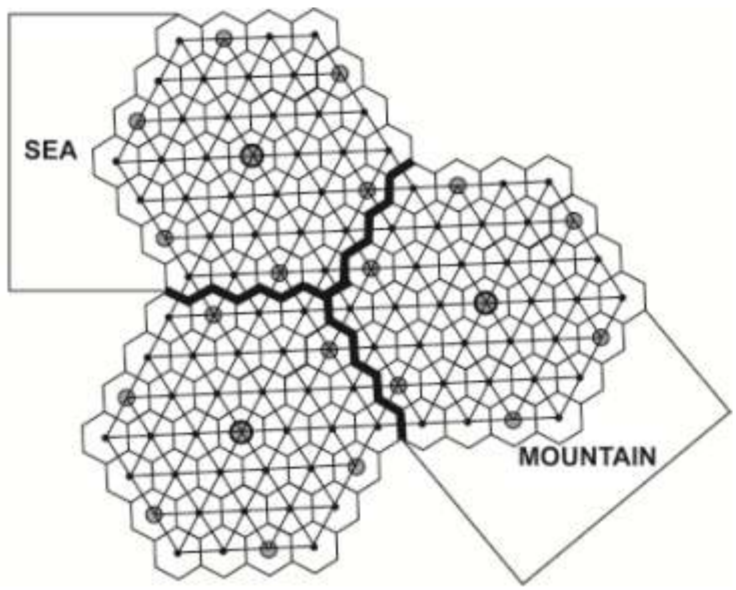

Figure 1: The Isolated Continent.

Transport is considered as homogeneous and isotropic, which supposes that the cost is the same in every direction. The transport cost is normalized by a vertice, and d_{ij} is the shortest path along the Delaunay graph, as shown in Figure 1. Besides, d_{ii} is chosen to be a quarter, which is taken as the differential ratio between time cost for people commuting within a functional urban area and people commuting toward an urban center).

The environment described above and the populations allocated to each city are the two determinants in agents' location. Indeed, every place is exogenously endowed with a population P_i, following a Zipf law (Sanders et al., 2006). P_n is the total population of a nation and P the total population of the system. Moreover, $P_1 = P_2 = P_3$ so as every nation is made of similar structures and population.

Such as in the EMU, every nation *n* in the model produces its own coins. The total number of coins *C* is:

$$C = \sum_n C_n$$

It has been shown in (Le Texier 2011) that euro coins don't behave similarly according to their values. Small and high coins are differentiated in this sense in the model: *v* = 1; 2; 5; 10; 20 cents et *V* = 50; 100; 200 cents. Still from empirical evidences (the euro coins production within the EMU) we know that the proportion of the small values represent two thirds of the total. Each agent has got a money-bag c_v of small coins and c_V of big coins. At the beginning of the simulation, the size of the money bag is identical among the population. This implies that:

$$C = \sum_n ({c_v}^{t0} + {c_V}^{t0}) P_n \text{ where } c_V = \frac{1}{2}\, c_v$$

If populations are chosen to be different between nations, then these differences will be observed between coins production as well, since importance is given to the constancy of the number of coins distributed among agents. The primary size of the money-bag is thus dependent of neither individual nor national richness.

2.2 Agents

One of the hypotheses of the model is that mobile people are the only ones who allow the brewing of the coins. The mobile agents are considered to be working people. As students and young retired are considered in this model as sharing the same activities than working people, the main criterion is age: people from 15 to 64 are considered as mobile agents. The immobile agents are defined as a mass of inertia attributed to every city under the form of a certain rate: they don't move but interact with the mobile agents. The respective importance of the both subpopulation is fixed according to the characteristics of European population. We assume that mobile agents have four types of mobility which will be described in 2.3.

According to Beaverstock (2004) analysis of the intercity career trajectories of managerial elites and Taylor et al. (2002) creation of intercity matrices from the location strategy of producer service firms, white collars, through their business trips, are one of the main driving forces of transnational flows between international cities. Their proportion in the mobile population will be fixed to 10%, which corresponds at the weight of managerial elite and academic professional within the French population (National French Survey 2006).

Thus, in this model skill is assumed to be the main driver of work and leisure mobilities (through business trip and income). As it is often considered in literature when it comes to differentiate labor, two types of skills are taken into account in the model: low and high, giving birth to a second categorization of mobile agents: w (white collars) and b (blue collars). This hypothesis is mostly based on works from the geographical economics literature, which often observe workers interregional mobility through the prism of high and low skills (see for instance Pas (1984); Pissarides and Wadsworth (1989); Korsu and Wenglenski (2010)).

The model proposes four types of mobility, whose appearance depends on a given timeline: business (I), commuting (II), multipurpose activities (III), and tourism (IV). The agent-based model is thus discrete in time. Unlike the use in urban mobility and transport models, the scheduling of activities is not integrated in a single Nested Logit Model or discrete choice models like in Adler and Ben-Akiva (1979) or in Kitamura (1984), for instance. The choice of an activity is here defined by a timeline whose steps are days. The timeline constrains the type of mobility of agents by defining a main activity in the day. As it has been depicted by many authors (Stock and Duhamel, 2005; Bell and Ward, 2000), for instance, touristic flows are mostly happening according to seasonality. Thus, months are defined according to work and holidays periods. During two weeks in winter and two months in summer, mobile agents are allowed to go in holidays, depending of an annual budget of holidays. Weeks are split into two categories of days: the week days (going from Monday to Friday) during when agents work (they may commute or go in business trips) and the week-end during when agents are making local multi-purposes trips (shopping, leisure, etc). Figure 2 represents the successive behavioral choices potentially made by an agent during one iteration of the model.

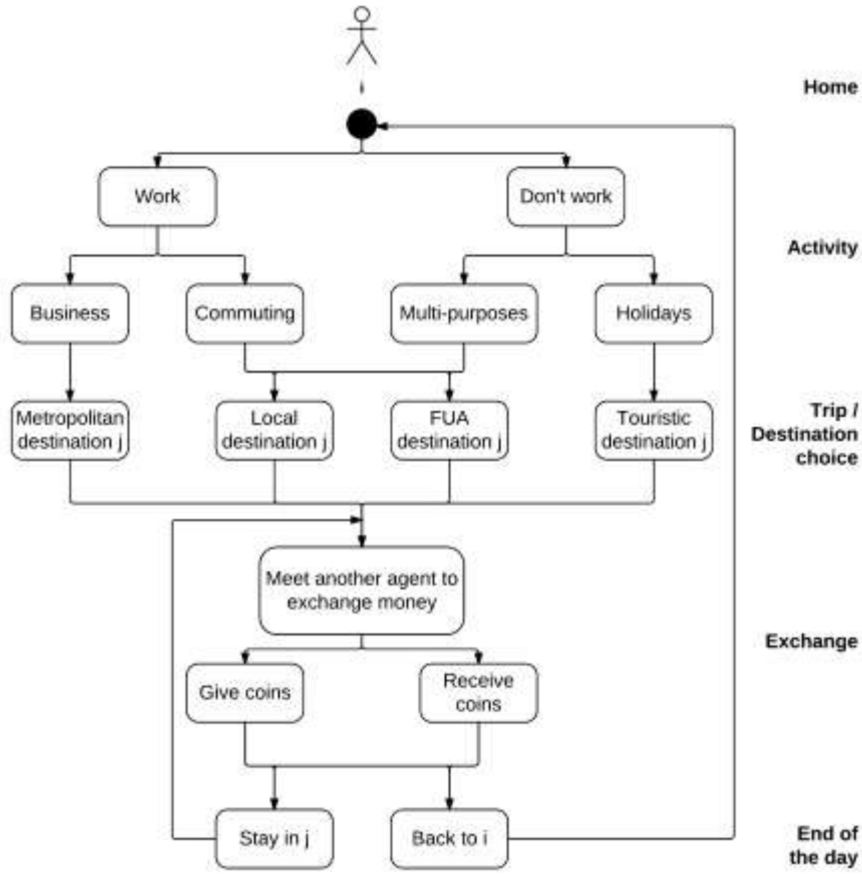

Figure 2: Activity diagram.

2.3 Trips and destination choices

Once the activities have been scheduled, the second step is to choose a destination. The decision process related to mobility follows a simple gravitational model which is expressed in a probabilistic manner as in Huff (1964) (i.e. it determines the probability for each place to be frequented). The general formulation of a destination is thus defined in the model as:

$$p_{ij} = d_{ij}{}^{-\alpha} P_j{}^{\beta} A_j{}^{\gamma} \Big/ \sum_k d_{ik}{}^{-\alpha} P_k{}^{\beta} A_k{}^{\gamma}$$

where:

- p_{ij} is the probability for people living in i to go in j
- d_{ij} is a topological distance between i and j (as discussed in 2.1)
- $\alpha \geq 0$ is a distance decay parameter
- P_j is the population of city j
- $\beta \geq 0$ is a population weighting parameter
- A is a specific attribute of places, independent of population, e.g. touristic attributes
- γ is the weighted parameter of attribute A

Business trips concern white collars only. It is assumed that the restraint due to distance is much lower than the one of commuting trips or multi-purposes trips. Besides, the attraction played by the size of cities is high:

$$\gamma_{I,w} \in [0\,;+\infty[\;\;;\; \alpha_{I,w} < \alpha_{II,w} \;;\; \beta_{I,w} > \beta_{II,w} = \beta_{III,w} = 0$$

Activity types 2 & 3 can be either realized within the settlement of residence or the Functional Urban Area (FUA) than we consider as an agglomeration of settlements organized around a main centre. In the first case, only the distance to be reached matters and this last one is constrained to a certain neighborhood:

$$\alpha = \beta = \gamma = 0 \ \forall \ d_{ij} \leq \theta$$

Trips realized within the FUA (Functional Urban Area) are somehow polarized by the main urban pole of the neighborhood such as both the size of cities and the distance to be reached constrain the destination choice:

$$\beta \neq 0 \ ; \ \alpha = \gamma = 0 \ \forall \ d_{ij} \leq \theta$$

Holidays trips are always made toward touristic destinations which are unequally distributed among places. High skill workers are less handicapped by distance in their choices for holidays than low skill ones:

$$A = 0 \ or \ 1 \ ; \ \gamma = 1 \ ; \ \alpha_{IV,w} < \alpha_{IV,b}$$

2.4 Exchange

Once people have moved to a particular place, they meet the immobile people of this city as well as the other migrants. To keep the model as simple as possible, it is considered that agents may only take part in an exchange once per time step. Pairs of agents are randomly made within cities. Pairs of agents are randomly selected from the population at destination within each city. If total population is uneven, one agent is left aside from the exchanges. Every agent is included in a pair and participates to one exchange per day. This is a high simplification to say that there is only an exchange per day and that everybody participates.

Further, we assume that there is equal probability to interact with someone from another social group through shops. In fact, we think that this is reasonable to think that most of the coins exchanged are independent of social networks: people exchange coins with shops' keepers, with taxi drivers, through coffee machines, etc and rarely through a direct contact. Eventually only mobilities' types and geographical environment differentiate money bags.

An exchange is made of a pair of agents and we decide that only one of them receives. We then define a receiver and a giver. The exchange being directional, the money bag of the receiver does not impact on the exchange process. Besides, the system has no memory, which implies that the giver/receiver probabilities are independent from each other and along time. The number of type of coins exchanged is constrained by the giver's money bag. Denote the number of coins exchange by:

$$x = x_v + x_V$$

where:

- x_v is the number of small value coins exchanged
- x_V is the number of high value coins exchanged

The amount of money exchanged is defined to be smaller than the amount of money contained in the money bag, thus no debt is allowed:

$$x_v < c_v \ ; \ x_V < c_V \in \mathbb{N}$$

x_v , x_V are taken randomly from a normal distribution with $\mu_v < \mu_V$, the mean of the distributions, and $\sigma_v = \sigma_V < 1$ the respective variances. These differences between average probabilities come from empirical observations. Indeed, it has been demonstrated that small coins diffuse less than high ones (Grasland et al., 2005; Le Texier, 2011). Nuno et al. (2005) and primary empirical results have also shown that the probability to choose more or less coins within an exchange is independent of individuals characteristics such age, genre or salary.

3. CONCLUSION & PERSPECTIVES

The model presented in this article will be the subject of an implementation in Scilab. The model is constructed in a learning perspective, meaning that its evaluation will be a continuous process. As the diffusion of euro coins is related to the idea of innovation, the focus will be shifted on the presence of foreign coins in individual moneybags. The final stage of the diffusion process is theoretically obtained when all coins are perfectly mixed and their proportion remain stable across borders: the simulation will end when the statistical distributions of foreign coins among agents and cities will have reached their maximal entropy. The main aim of this study being to isolate the key paths to transnational mobility and individuals mixing within the European Monetary Union, the results of the simulation will be compared with data on pursues' contents collected by the ESDO and CEPS-Instead projects in France (15 surveys from March 2002 to October 2008), Belgium (December 2003), Germany (December 2004) and Luxembourg (June 2006) on an average of 2000 respondents per survey. Finally, the spatial structure of the model will be transformed to better fit to the French-German-Belgium-Luxembourgish area (addition of a language barrier within a country, monocentric versus polycentric national cities system, etc).

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