JASSS

Francesca Borrelli, Cristina Ponsiglione, Luca Iandoli and Giuseppe Zollo
(2005)

# Inter-Organizational Learning and Collective Memory in Small Firms Clusters: an Agent-Based Approach

*Journal of Artificial Societies and Social Simulation* vol. 8, no. 3
<http://jasss.soc.surrey.ac.uk/8/3/4.html>

For information about citing this article, click here

Received: 12-Jan-2005 Accepted: 30-May-2005 Published: 30-Jun-2005

## Abstract

Literature about Industrial Districts has largely emphasized the importance of both economic and social factors in determining the competitiveness of these particular firms' clusters. For thirty years, the Industrial District productive and organizational model represented an alternative to the integrated model of fordist enterprise. Nowadays, the district model suffers from competitive gaps, largely due to the increase of competitive pressure of globalization. This work aims to analyze, through an agent-based simulation model, the influence of informal socio-cognitive coordination mechanisms on district's performances, in relation to different competitive scenarios. The agent-based simulation approach is particularly fit for this purpose as it is able to represent the Industrial District's complexity. Furthermore, it permits to develop dynamic analysis of district's performances according to different types of environment evolution. The results of this work question the widespread opinion that cooperative districts can answer to environmental changes more effectively than non-cooperative ones. In fact, the results of simulations show that, in the presence of turbulent scenarios, the best performer districts are those in which cooperation and competition, trust and opportunism balance out.

**Keywords:**
Firm Networks, Collective Memory, Agent Based Models, Uncertainty

## Introduction

**1.1**
The notion of Industrial District (ID) was introduced by Alfred Marshall in 1919; he identified the external economies for the firm as a crucial factor of competitiveness for localized systems of specialized small and medium enterprises. Nevertheless, only after World War II we saw a "renewal" of the ID's model in the economic thought.

**1.2**
Becattini (1979) identified the ID as an elementary and autonomous unit of analysis. The ID conceptualization proposed by literature (Aydalot 1986; Becattini 1989; Brusco 1982; Camagni 1989; Camagni 1991; De Rosa and Turri 2002; Fuà and Zacchia 1983; Garofoli 1978; Rullani 1992) is characterized by two central elements:

- ID's structure is based on a dense and strong network of relationships among autonomous and heterogeneous agents (firms, families, local institutions);
- ID's competitiveness can be attribute to the co-evolution of district's productive organization and of local formal and informal institutions.

For thirty years, the ID productive and organizational model represented an alternative to the integrated model of fordist enterprise. Nowadays, the district model suffers from competitive gaps, which are largely due to the increase of competitive pressure related to globalization phenomena.

**1.3**
This work aims to analyze, through an agent-based simulation model, the influence of informal socio-cognitive coordination mechanisms on district's performances with respect to different competitive scenarios, whereas the most recent applications of social computation to firms clusters and supply chains are usually focused on productive and managerial coordination mechanisms (Boero and Squazzoni 2001; Strader, Lin and Shaw 1998; Péli and Nooteboom 1997).

**1.4**
In general, agent-based simulation enables to analyse self-organising systems, learning systems and systems with high complexity. With reference to the latter, Arthur, Durlauf and Lane (1997) identify the following elements characterising Complex Adaptive Systems

(CAS):

- wide interaction among agents operating at local level;
- lacking of a central controller;
- multi-level organisation with distributed interactions;
- continual adaptation;
- presence of turbulent elements (new markets, new technologies, new behaviour);
- bounded rationality;
- agents adaptation and continuous evolution.

These elements can be easily found in the ID's model; in fact IDs are adaptive learning agent-based systems with bounded rationality, where agents interact at different levels, in other words are Complex Adaptive System.

## Background

**2.1**
In section 2.2 some recent applications of agent-based models to IDs and firms' networks are reviewed, in order to place the contribute of this work in the research agenda about the development of models to study IDs' dynamics. Section 2.6 reviews main literature approaches to IDs, in order to outline the theoretical underpinnings of the proposed agent-model.

### Modeling firms networks and ID through agent-based simulation: a review of existing approaches

**2.2**
In this paper, the dynamic analysis of IDs is made up through an agent-based computational approach.

**2.3**
Some recent researches proposed the agent-based approach to the analysis of IDs, firm's networks and supply chains (Boero and Squazzoni 2001; Strader, Lin and Shaw 1998; Péli and Nooteboom 1997). Such applications show a similar architectural platform. This platform is based on five conceptual blocks:

- classes of agents (entities);
- agents, in terms of objectives and rules of evaluations and decisions;
- environment structure;
- interaction context;
- structure of the information flow.

Table 1 summarizes the characterization of these blocks with respect to some relevant recent applications selected as examples.

**Table 1:** Examples of simulation models applied to IDs, firms' networks and supply chains

| | | **Authors** | |
|---|---|---|---|
| | Boero, Squazzoni (2001) | Péli, Nootebom (1997) | Strader *et al.* (1998) |
| **Building blocks** | | | |
| 1. Entities | Firm's classes (final firms and sub-contracting firms) of an industrial district | User firms and supplier firms | Supplier, manufacturers, assemblers, distributors, and customers |
| 2. Agents (algorithms and goals) | Technology absorption, learning dynamics | Learning dynamics: learning by doing and learning by interacting | Decision making rules. Demand management policies (MTO, ATO, MTS) |
| 3. Environment structure (exogenous laws) | Technology and market as selection mechanism | Technology and market structure | Demand structure |
| 4. Interaction context | **Production chain, spatial and organisational proximity** | **Supply partnership** | **Divergent assembly supply network** |
| 5. Information | External environment/agents; | External environment/agents; | External environment/agents; |

| | | | |
|---|---|---|---|
| flow | agents/agents | agents/agents | agents/agents |
| 6. Purpose of simulation | To analyse firm's adaptation and system evolution with respect to market and technology environment challenges | To explore the trade-off between a single or multiple sourcing | To study the impact of information sharing on order fulfilment in divergent assembly supply networks |

The first application refers to the modeling of an ID prototype; the second example refers to the analysis of supply partnerships' performances through an agent-based platform; the third application is focused on studying divergent assembly supply chains.

**2.4**

The first application is very close to the problem faced in this work and give us some useful suggestions to develop an agent-based model to study IDs' dynamics. On the other hand, it is important to outline that these approaches are mainly focused on the impact of formal coordination mechanisms on firms' performances usually evaluated with respect to operations management and production issues (Boero and Squazzoni 2001; Strader, Lin and Shaw 1998; Péli and Nooteboom 1997).

**2.5**

In particular, in Boero and Squazzoni's (2001) model, coordination mechanisms are related to spatial and organizational proximity. The spatial proximity is the proximity among agents belonging to a same class of agents, the organizational proximity is the proximity among firms belonging to the same productive chain of the district. Little attention is given to social coordination mechanisms as culture, values, beliefs, interpretative schemata. However, the main focus of most of the researches conducted on IDs, both at the theoretical and empirical level, has been the network of inter-firm relations; the network of inter-firm relations has been the key to understand the peculiarities of district model. ID's competitiveness is mostly attributed to the strictly combination of enterprises, people and families, to the presence of both cooperation and competition mechanisms, to the existence of spontaneous coordination model based on strong values like trust and reciprocity (Becattini 2000).

**A socio-cognitive perspective to agent-based simulation of ID**

**2.6**

Within the debate on small firms, ID is pointed out as an example of the flexible specialization model (Piore and Sabel 1984). Piore and Sabel (1984) emphasized the ID model as an example of production model characterized by flexible specialization and able to compete with the large integrated enterprise. The approach of these two authors is mostly focused on the productive interdependence of district's firms, on the aspects of productive system, but it only mentions the importance of cultural factors and coordination mechanisms of the district.

**2.7**

According to the economic approach to the analysis of cooperative relationships, the Transaction Costs Economic Theory (Coase 1937; Williamson 1975) considers inter-firms relations as relations of mere economic exchange, based on calculation and optimization, guided by an instrumental logic to achieve personal interests. The transactional approach has shown to be inadequate, because of its pure economic nature, to face the complex nature of the embedded organizational and social processes which characterize the modern productive systems (Uzzi 1996).

**2.8**

ID's development is based on a strong relation between production and social system, on spontaneous and informal transactions, on sharing of norms, frameworks of references, cultural rules, reciprocity and trust. In order to study the organizational structure, the nature and dynamics of relations that evolve inside IDs, it is necessary to find a more appropriate theoretical approach, which can consider the importance of institutional factors (norms, values, culture, routine).

**2.9**

A more adequate approach which follows the last organizational developments related to complexity is the collective and cooperative networks approach (Rullani 1989; Sako 1992; Granovetter 1985; Powell 1991), which has been declined, for regional systems analysis, in the concept of the milieu innovateur (Camagni 1989).

**2.10**

The milieu is defined as "a set of local relationships, which fasten together in a coherent productive system, different social actors, a specific culture and framework of reference and contribute to a dynamic and continuous process of collective learning" (Crevoisier, Maillat and Vasserot 1989; Ratti and D'Ambrogio 1989).

**2.11**

The milieu is able to reduce the environment uncertainty through the following functions:

- informal coordination of decisional processes;
- collection and collective evaluation of information;
- reporting toward local markets, in terms of trust and reputation;

- collective learning improved through imitative processes and local human resources' mobility;
- collective definition of managerial styles and decisional routines, thanks to the important role of local collective institutions as local trade associations;
- informal coordination of decisional processes, through interpersonal links, information transparency, fast circulation of information's flows.

Finally, the milieu innovateur approach emphasizes the importance of spatial and cognitive variables in determining ID's capability to answer effectively to the turbulence and to uncertainty of competitive environment. Therefore, the competitive characteristics of IDs are strictly related to horizontal socio-cognitive coordination mechanisms.

**2.12**

This approach to the analysis of inter-firm relationships can be referred to an institutional theoretical framework (Scott 1995). According to this framework, organisations are embedded in an institutional context: each organization is supported by institutional forces and, at the same time, includes institutional elements as culture, routines, norms and values. The local milieu can be considered as an institution generated by processes of social interaction. The coordination of district relationships occurs by means of informal institutional mechanisms, such as reputation, trust, mutual learning, cooperation, etc, mainly of social and cognitive nature.

**2.13**

Then, how to translate these social and cognitive coordination mechanisms into an operational construct that can be implemented through an agent-based model? A possible answer to this question can be formulated by introducing the concept of "district collective memory", as outlined in the following section.

## IDs as collective cognitive systems

**Institutions and collective memory**

**3.1**

A theoretical rationale for the introduction of the concept of collective memory of ID can be based on a socio-constructionist perspective. According to Berger and Luckmann (1966), institutions are the product of the accumulation of collective knowledge. The main characteristics of any durable social aggregation lies in the progressive construction of consuetudinary social practices: the repetition of individual actions into a collectivity allows members of the group to describe action through established schemata that may be applied by individuals in suitable circumstances to predict other members behavior and actions.

**3.2**

Repeated practices allows group members to achieve, through individual contributions, super-individual objectives, such as the survival of the group and its continuity. When individual action is repeated through shared schemata, a process called "routinization" takes place. In the long term, routinization generates reciprocal expectations among group members concerning individual behaviors and makes social action impersonal and anonymous since it is linked to social roles rather than to particular individuals.

**3.3**

In other words, (1) habits make a basis for the division of social tasks among group members, (2) tasks are attributed to specific individuals and are executed according to shared patterns of action; (3) in the long run, repetitions and routines become anonymous, impersonal and objective and are not more related by group members to a specific individual but rather to a social roles having certain attributes and characteristics, (4) this impersonal but shared knowledge that is built through social action ultimately influence individual behavior.

**3.4**

Routinization and anonymity are not sufficient to create an institution if other two characteristics are lacking: first, institution must have a "history", second, institution must provide individuals with behavioral guidelines to which they are request to adapt. Consequently:

a. institutions are the result of a process of collective accumulation of knowledge that is created through repeated interactions taking place during an evolutionary development process;
b. such collective knowledge influences individual behaviors since it provides individuals with behavioral guidelines and shared values;

**3.5**

Then, the institutional approach to ID permits to conceptualize such body of shared knowledge as a collective memory and to posit that shared memory does play a role in shaping relationships between firms belonging to IDs. If individual behaviors in ID are influenced by past knowledge accumulated both into a collective and subjective memory, then modeling ID by only considering current firm-to-firm and firm-to environment interaction is reductive and not realistic. For example, due to the presence of a strong collective memory, the ID may experience inadequate capability to react to sudden changes that could be hardly explained by agent-based models in which only current interactions is considered.

**3.6**

But, if collective memory has to be considered as a relevant social coordination mechanism, it is necessary to identify possible ways through which such a concept can be described and represented into an agent-based model.

**Toward an operationalization of collective memory**

**3.7**

Knowledge accumulation through time by individual within more or less structured collectivity has been largely investigated in organizational literature, as partly already outlined in sections 2.2 and 3.1.

**3.8**

According to a knowledge-based approach to the theory of the firm (Fransman, 1994), companies are "repositories of knowledge" (Penrose 1959), systems integrating specialized knowledge (Simon 1961) able to preserve and generate knowledge (Grant 1996), systems able to learn through trial and errors process (Herriot, Levintal and March 1975) and that build and select routines (Nelson and Winter 1982). Schein (1985) argues that the accumulation of social practices produces the creation of a collective culture, i.e. a set of basic assumptions shared, invented or developed by a group in the attempt to resolve a trade off between external adaptation and internal integration, that have proven to be successful and that must be taught to new members of the group as the right way to perceive, think, behave in certain specific circumstances.

**3.9**

Though such studies all emphasize the role of past knowledge and of knowledge exchange and creation within collectives and provide many useful elements to concretely characterize how social cognition takes place, they do not make an explicit reference to collective memory, nor they propose an operative definition of such concept.

**3.10**

A notable exception is represented by the work by Walsh and Ungson (1991), in which a model of organizational memory is proposed. In particular, they assume that organizational memory has a distributed structure made up by the connection of both tangible and intangible "retention facilities" in which knowledge and information are stored within organizations: organizational structure, transformations (i.e. production routines), ecology (i.e., work physical environment), organizational culture, external archives.

**3.11**

The model proposed by Walsh and Ungson can hardly be adapted to ID since it is conceived at an organizational level of analysis rather than at the inter-organizational one. Furthermore, in their effort to make tangible and analyzable the collective memory, Walsh and Ungson do not investigate the socially constructed nature of collective memory and the dynamics through which it is constructed, modified and evoked by social actors.

**3.12**

On the bases of the above theoretical considerations and existing literature about knowledge accumulation within organizations and firms networks, we propose the following definition of collective memory in ID and firms networks: *the set of shared social practices and values influencing social behavior through long term learning processes based on repeated interaction and on the sharing of a common patrimony of resources, production routines, competencies, values and objectives*. The operational construct of the collective memory is made up by the following elements:

a. *values*: values represent shared beliefs about what is considered good and desirable both from an ethical and practical point of view. For example, values may be referred to business ethic, social accountability, acceptable behaviors and conduct. Values have to be considered as situated and specific of a given social milieu and as premises for action;
b. *production routines*: such routines are the way through which firms combine inputs and realize their outputs through the implementation of production processes;
c. *resources*, representing inputs for production. Even if in some cases resources can be objectively described, what is a resource and what is not and which attributes such resources should posses is often a matter of tradition in ID;
d. *competencies*, representing firms technical and market know-how and capabilities developed through long term expertise and professional development;
e. *strategies*: the kind of strategic objectives here meant as the "right way" to compete is also learnt and transmitted as shared knowledge. Actually, it is well known that strategic behaviors of firms belonging to embedded networks such as ID tend to be similar.

**3.13**

If, on one hand, such elements alone do not represent an exhaustive description of a complex concept such as collective memory, on the other hand they encompasses the main elements above outlined. Furthermore, such elements can be assumed as relevant components of the collective memory in that:

- they embody knowledge that a collectivity has accumulated, codified and institutionalized by consolidating past experience;
- such knowledge, described in terms of values, production routines, resources, competencies and strategies, is evoked by firms in the course of action to make

decisions and evaluations;
- collective knowledge ensures the stabilization and permits the reproduction of social action through time;
- values, production routines, resources, competencies and strategies are preserved and maintained through time.

**The theoretical model**

3.14

The model depicted in Figure 1 is made up by the following conceptual blocks: collective memory, agents models, environment structure and information flow. The model also helps to clarify the role of collective memory in agent-based models.

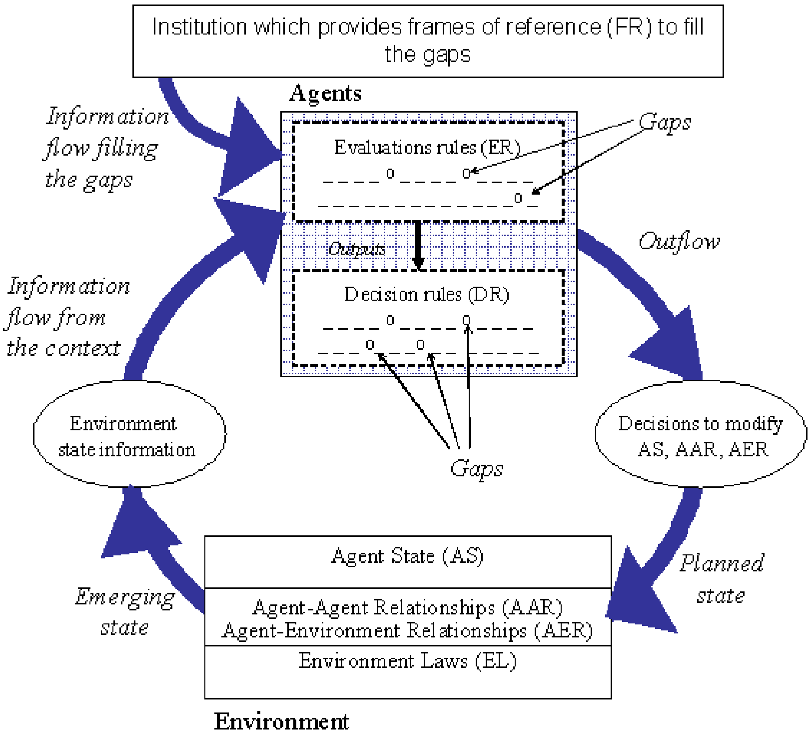


**Figure 1**. The role of collective memory in agent-based models of ID

**Collective memory**

3.15

According to the model of Figure 1 agents can be suppliers or final firms in an ID. Firms are provided with bounded rationality in the sense that usually they have to cope with incomplete and ambiguous information when making decisions. In order to cope with such a limitation, agents evoke collective knowledge stored in the collective memory. Collective memory provides agents with default knowledge useful to cope with recurring and stereotypical situations. Thanks to these default knowledge agents can make decisions even when information is partial or ambiguous by activating well known routines and behaviors. In other words, the presence of a consolidated knowledge patrimony refined through experience and reinforced by consensus helps firms to overcome lack of information by recurring to tradition and routines. If on one hand, collective memory may imply a sort of cognitive economy for firms, on the other hand, in presence of novel and unpredictable competitive scenarios it may turn into a cognitive rigidity and incapability to innovate and react to sudden environmental changes.

**Agent models**

3.16

Agents (firms) are described by a set of variables (competencies and state variables), evaluation and decision rules. Competencies represent firm skills, knowledge and capabilities, while state variables represent their internal resources and values. During simulations, firms might decide to improve their competencies by comparing their current levels of competencies with target ones; these latter imposed by the market. Firms have a bounded rationality and the acquisition and processing of information is costly. For this reason, firms face investment trade-offs, regarding to the selection of the competencies to be improved. Only in the decisional phase firms will be able to select the competencies to be improved and the strategies to be implement.

**Environment structure**

3.17

This conceptual block entails some elements pertaining to the competitive environment of an ID. One is the inter-firms scaffolding structures (Boero and Squazzoni 2001) needed to co-ordinate production processes. In our model, final and subcontracting firms are not able to sell their products alone. Nevertheless, they can interact to exchange information, materials and products. Through this exchange, they are able to sell their products on the market. Thus, the interaction context of the model is represented by district's supply chains; the latter will be indicated as "production chains" (Becattini 2000).

**3.18**

In our model, target competencies are determined by market requirements. We assume that the market carries all needed information to develop attractive products. At some point in the simulation, product quality may increase, driving firms to improve their competencies in order to meet the new quality standards. With this approach, firms competencies levels adapt over time in order to maximize their performance, since the profit is function of product quality.

**3.19**

Different market segments will be progressively introduced, during the simulation, in order to model market turbulence. In fact, one of the purposes of this work is to analyze how firms face market turbulence and how long it takes them to reach new competencies levels.

##### Information flow

**3.20**

The proposed model assumes that final firms have higher strategic capabilities than subcontracting ones; this is translated in final firms capabilities in converting market inputs (competences target levels) into internal information (Boero and Squazzoni 2001). The information and production flows are structured as follows:

- final firms receive external information from market about products requirements (competencies target levels);
- subcontracting firms receive product requirements interacting with final firm;
- production chains assemble and sell final products to market and receive a profit, which is function of product quality.

## The Computational Model

**4.1**

In this section, we illustrate the computational model used in the simulations. The computational model is based on the theoretical model above. The theoretical model has been translated into agents models, rules of behavior, communication and interaction mechanisms of industrial district's firms, by considering all the elements included into the collective memory (values, competencies, resources, strategies, production routines).

**4.2**

The computational model has been implemented by AgentSheets® platform. AgentSheets applications include a collection of autonomous computational processes, called agents that can be characterized in terms of different looks and rules of behaviors.

**4.3**

Agents are placed together in a 2-D grid, the worksheet, where they interact with each other. Cells in a worksheet can contain multiple agents. Agents interact in a worksheet by checking conditions, based on information about themselves or on information obtained from agents in other cells, and executing those actions whose conditions are met (Repenning, Ioannidou and Zola 2000). A copy of the AgentSheets code may be downloaded here. AgentSheets is available for Windows and Macintosh computers.

### Agents

Agents are all the elements which take part in the simulation model. We classify them into two typologies:

- principal agents
- second order agents

In our model principal agents represent ID firms. Second order agents have been created to translate in computational terms the structure of the environment and of information flow in ID. They are designed with a top-down perspective (Conte 1999). This means that we know how they vary during simulations.

##### Second order agents

**4.4**

Second order agents are essential to model the environment structure and the information flow in ID.

###### The ground

In our model, the ground plays the role of communication and information processing mechanisms of the specific context of the industrial district modeled. In fact, ground agent:

a. defines the physical space where ID firms (final, subcontracting and production chain)

act (move, interact, etc. - see Figure 2).
b. diffuses and store information in the ID. The ground agents spread information in ID through diffusions processes. In the model, we designed a diffusion process for each type of information to be broadened (see paragraph 4.13) on the district.

Firms can make decisions by using information they recall from interaction with the ground agent; the information is necessary to deal with environment uncertainty and vagueness.

##### Market Segments

To translate, in computational terms, the role of the environment structure we define three market segments: $S_1, S_2, S_3$. These segments represent the potential markets for ID firms. Different levels of competencies characterize each market segments: $S_i = (M_i, T_i, P_i)$. Where $M_i, T_i, P_i$ represent the highest level of competencies required from the market at iteration *i*.

**4.5**

We assume that at the beginning of a simulation exists only $S_1$. At certain iteration of the simulation, first $S_2$ and then $S_3$ appear on the district. The ground agent spreads the information relative to target levels required by market segments (see paragraph 4.13). Firms agents interacting with ground agents perceive the existence of different market segments and can select which one to pursue. Firms, which decide to move from $S_1$, to $S_3$, have to increase their competency levels; thus, they have to invest part of their economic resources. On the other hand, they are encouraged to perform this step for the higher profitability of $S_3$. As example, the three segments market might stand for: local market, national market and international market.


**Figure 2**. The simulation work space - AgentSheets worksheet

##### Principal Agents

**4.6**

According to flexible specialization theories (Piore and Sabel 1984; Saba 1995), we modeled an ID as a system of small and medium firms, which interact to realize a final product. We define three classes of principal agents: final firms, subcontracting firms and production chains.

**4.7**

The principal objective of final firms (*fin*) is to meet market requirements; they try to achieve this objective by building up efficient production chains. Production chain efficiency is measured in terms of achieved quality during the production phase and production costs. Subcontracting firms (*sub*) are production phase firms providing raw materials, components and semi-finished products to final firms. Their objective is to search for an adequate final firm in order to buildup a production chain.

**4.8**

The interaction structure between final and subcontracting firms is based on production chains (*Pch*). In our model, a production chain is formed by one final and one subcontracting firm. When a final and a subcontracting firm join together to generate a production chain they disappear from the model and they form a new agent called production chain, however without loosing their individual characteristics. Firms belonging to the same chain exchange information and products, in order to accomplish the production process and to sell the product/service to the market. The objective of production chains is to sell their product to the market, and to seek for more and more profitable markets.

**4.9**

Principal agents are modeled, in computational terms, as state variables, competencies levels, economic resources and evaluation and decision-making rules. These elements structure principal agents' inner models. Describing inner models means to explicit how agents perceive and react to external environment information.

**4.10**

Each agent is characterized by an internal state (IS), which is an instantiation of its state variables, competencies levels and economic resources. This state progressively changes in each iteration (called 'cycle') of the simulation, accordingly to firm choices and interactions with the other agents of the model. Thus, for the cycle *i-th*, firm's internal state (IS($S_i$)) is function of:

$$IS(S_i) = f(m_i, t_i, p_i, opp_i, risk_i, bdg_i)$$

where:

- $m_i$ represents the level of market competencies.

  Market competencies group all the skills, knowledge and capabilities of the firm to sell its product to the market. Production chains with higher levels of $m_i$ have more probabilities to sell their product to the market. For final and subcontracting firms improving $m_i$ levels means increasing their probabilities to be approached by a potential partner.

- $t_i$ represents the level of technical competencies.

  Technical competencies are strictly related to product quality. Firms with higher level of $t_i$ are able to manufacture better products (as we identify market requirements with quality standards). Technical competencies are related to the specific production routines firms implement, so their level has to be measured accordingly.

- $p_i$ represents the level of relational competencies.

  Relational competencies gather several competencies, like partner selection, alliances creation, organizational competencies within production phases, information exchange. Final and subcontracting firms with higher levels of $p_i$ show better capabilities to cope with other firms to generate a production chain; while, for production chains, high levels of $p_i$ indicate that the firms belonging to the chain can cooperate fairly well, in order to generate a good outcome.

Competencies variables ($m_i$, $t_i$, $p_i$) are measured on a discrete point scale ranging between 1 and 9, where 1 indicates the worst value. Competencies are part of the collective memory of the ID; so their levels and their descriptions have to be represented by keeping into account the characteristics of the specific ID being modeled.

When the simulation starts we assume that ID is populated only by final and subcontracting firms having certain initial values of competencies levels ($m_0$, $t_0$, $p_0$). Instead, for production chains the initial values ($m_0\_pch$, $t_0\_pch$, $p_0\_pch$) are determined when the chain is built up. We assume that when a production chain is formed, it inherits the highest levels of competencies between the firms that generate the chain. In detail:

- production chain market competencies: $m_0\_pch = max(m_i\_fin; m_i\_sub)$
- production chain technological competencies: $t_0\_pch = max(t_i\_fin; t_i\_sub)$
- production chain relational competencies: $p_0\_pch = max(p_i\_fin; p_i\_sub)$

One of the main objectives of district firms is to achieve the target levels of competencies required from the market.

- $opp_i$ Degree of Opportunism and $risk_i$ Risk Propensity.

  Another element of the collective memory is given by values representing shared beliefs about what is considered good and desirable both from an ethical and practical point of view. For the sake of simplicity, in our model, we consider only two values: opportunism and risk propensity. Firms' attitudes towards these two behavioral dimensions are recognized as main determinants of economic behavior (Williamson 1985; Schumpeter 1934). Thus they can be used to model in a general way a large range of situations. However, the structure of the model is such that it is possible to include other value variables by keeping into account the specificity of the collective memory of a given ID.

  The *Opp* variable affects final and subcontracting firms' aptitude in building up a production chain; while, for production chain this variable influences its aptitude in breaking up the chain. This is a binomial variable, assuming values (0, 1). "Zero value agents" have a low degree of opportunism, while "unit value agents" have a high value.

  Final and subcontracting firms with high values of opportunism will search for a partner with competencies levels greater or equal than their ones; while, low values indicate that firms will form chains without comparing the competencies levels. For production chain, instead, high values of opportunism indicate that it is less durable.

Risk propensity variable indicates agent's inclination to carry out investments. Firms with high values of this variable will set competencies improvements as primary objectives. *Risk* is a binomial variable, where values equal to one are defined as high.

- $bdg_i$ The budget function.

  This function computes the amount of economic resources of the firm. For each cycle, the function output (budget value) increases or decreases accordingly to firms choices; the function is defined as follows:

  $$bdg_i = bdg_{i-1} - C_{exp} - C_{inv} + PFT_i$$

  where:

  - $bdg_{i-1}$ is the budget value in the cycle $i$-1
  - $C_{exp}$ represents firm's *costs of exploration*. An agent spends economic resources for every movement it takes in the environment space. This cost is constant during the simulation.
  - $C_{inv}$ is firm's *costs of investment*. Firms have to invest some economic resources for every competencies improvement they perform. This cost is function of the level of competencies and decreases as competencies levels increase: $C_{inv} = f(C_{inv\_MAX} / m_i, t_i, p_i)$
  - $PFT_i$ indicates firm *profit* at cycle $i$. Profit is function of product quality. Firms that sell higher quality products will receive higher profit.

  At the beginning of the simulation, we settle the value of economic resources for all the final and subcontracting firms ($bdg_0\_fin$, $bdg_0\_sub$); for production chains this value is computed when the chain is formed, as follows:

  $$bdg_0\_pch = (bdg_i\_fin + bdg_i\_sub)/2 + P_{Pch} - C_{int} - C_{risk} - C_{opp}$$

  where:

  - $P_{Pch}$ is an amount of economic resources that the firms receive as an incentive for the generation of the production chain. This value is constant during the simulation.
  - $C_{int}$ is a cost of *integration* due to differences in firms competencies levels. This cost increases as differences in competencies rise: $C_{int} = 100*[(m\_fin - m\_sub)^2 + (t\_fin - t\_sub)^2 + (p\_fin - p\_sub)^2]$
  - $C_{risk}$ is a cost due to differences in risk values $C_{risk} = 100*(risk\_fin - risk\_sub)^2$. This cost should prevent the new production chain to face problems of opposite behaviors in investment choices.
  - $C_{opp}$ is due to opportunistic inclinations of the firms belonging to the chain $C_{opp} = 100*opp\_fin + 100*opp\_sub$. Thus, firms pay a cost to avoid opportunistic behaviors within the chain.

  In the same way, when a chain breaks up the budget value of the new firms is computed as follows:

  $$bdg_i\_fin = bdg_i\_sub = (bdg_{i-1}\_pch)/2 - C_{bk}$$

  where:

  - $C_{bk}$ is a penalty cost to pay for chain destruction. Its value is constant.
  - $bdg_{i-1}\_pch$ is the budget of the chain at cycle $i-1$.

**Simulation Steps**

**4.11**

At this point, we have to translate the information and production flows of the model. This means explicating the actions that principal agents perform at each iteration of the simulation (Figure 3).

**4.12**

In AgentSheets applications, agents' actions (searching, looking, sending messages, etc.) are defined by a set of *if-then rules*. We summed up these rules into six principal steps:

1. *Internal state check:*
   At the beginning of each cycle, firms check their internal state: IS($S_i$) = $f(m_i, t_i, p_i, opp_i, risk_i, bdg_i)$
   To limit complexity we assume that some of the state variables ($opp_i$ , $risk_i$) do not change their values during simulation. This is also to keep into account the inertia of collective memory. Instead, economic resources and competencies levels vary and derive from the previous cycles. In particular, if the amount of economic resources of a firm agent is less or equal to zero the agent dies and disappears from the simulation worksheet.

2. *Evaluations*
Firms evaluate their levels of competencies by comparing them to the target levels given by the market. They can compare these values from the interaction with the ground agent: firms, standing and moving on ground agents (see Figure 2), interact continuously with them and take from them information about the competences levels required by the market in the current cycle. Evaluation rules are translated as follows:

IF $m_i < M_i$ THEN eval ($m_i$) is *positive*
ELSEIF eval ($m_i$) is *negative*

where:

   - $M_i$ is the target level for market competencies at cycle *i*.
   - eval ($m_i$) represents the output of market competency evaluation process. A *positive* output means that the firm would like to improve its market competencies.

In the model, we defined three evaluation rules one for each competency level to assess. In this phase, district firms do not choose any strategy; they just transmit a message to the next phase: the decisional one.
3. *Improvement strategies*
In this step, firms choose their improvement strategies, according to internal state, evaluation outputs and objectives and set the direction for environment exploration (step 4). Firms have to decide which competencies to improve. Firms with enough economic resources will probably decide to make all the needed investments. However, generally, firms are constrained by their economic resources and are able to carry out fewer improvements than those demanded from the market. Firms face investment trade-offs. To get out from this situation, firms estimate the different profits they might obtain with different competencies profiles. In this way, firms with few economic resources will carry out those improvements that maximize the profit estimation. When, firms have selected the competencies, they implement the improvements processes. In computational terms, improvement processes are translated as follows:

IF *imp*($m_i$ ) is *positive* THEN $m_i = m_{i-1} + 1$ ELSEIF $m_i = m_{i-1}$

A positive improvement of market competencies (*imp*($m_i$ ) > 0) is converted in an increase of the related competence level ($m_i = m_{i-1} + 1$). Likewise, technological or relational competency improvements mean increases in technological or relational levels respectively. We make the simplistic assumption that when firms invest economic resources for competencies improvements they always get a higher level for their competencies. Moreover, each ID agent sets the "direction" (up, down, left, right) to move in the worksheet (step 4); principal agents use tracking mechanisms to accomplish this action (see paragraph 4.13).

4. *Environment Exploration*
Principal agents move on the worksheet to explore the environment and to achieve their objectives. Principal agents explore the environment, on the basis of the direction selected in the previous step. The firm agent makes one step per iteration toward the selected objective (agents can move only in one of the neighboring cells - up, down, left, right). Agents are required to invest economic resources to make any movements. Such investment represents the costs they have to bear for information search.
5. *Production chains generation or break up*
A fundamental objective for final and subcontracting firms is to become part of a production chain. To accomplish this result, they first verify if there are the necessary external and internal conditions in order to form a chain and then they select the partner. Internal conditions are matched when ID firms are not production chain. External conditions depends on firm position in the simulation space (the worksheet of AgentSheets). They are matched when a final and a subcontracting firm are next to one another. Final and subcontracting firms with high *opp* values search for a partner on the bases of competencies levels: opportunistic final firm will select only subcontracting firms with competency levels greater or equal than its own levels. Subcontracting firms are not able to select for final firm. However, they move closer to attractive (in terms of competencies levels) final firms in order to be selected by them. Final and subcontracting firms with low *opp* values tend to not break an existing chain when encountering potential partners having competences levels higher than the actual partner. In this step, production chains might decide to break up the chain, this decision is function of their opportunism degree. When a production chain breaks up, the agent chain (*Pch*) disappears from the simulation and a final and a subcontracting firm come out.
6. *Product sale*
Every production chain assembles and sells its product to the market and receives a profit when the market buys its product. The gained profit is a function of market segment profitability and of product quality; the latter is a function of the competencies gap of the firm. For each cycle *i* the profit is computed as follows:

$$PFT_i = PFT_{iMAX} - f(gap\_m_i; gap\_t_i; gap\_p_i)$$

where:

- $PFT_{iMAX}$ is the maximum profit firm might get at cycle *i*. This value is stable for each market segment and increases moving from $S_1$ to $S_3$.
- $gap\_m_i = M_i - m_i$, $gap\_p_i = P_i - p_i$ and $gap\_t_i = T_i - t_i$ represent the gaps between firm's competences levels and target levels at cycle *i*.

When the market doesn't buy the product from the chain, it does not receive any profit and it cannot increase its economic resources. Moreover, final and subcontracting firms cannot sell any products on the market, thus if they do not form a production chain they will sooner or later die during the simulation.

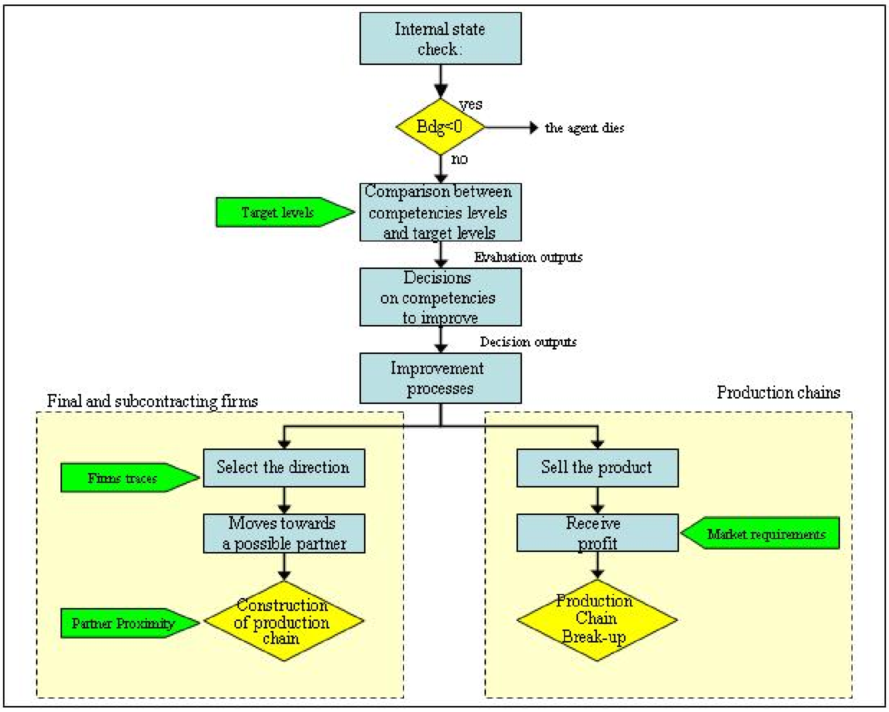


**Figure 3**. **Principal events of the simulation**

**Movements and Tracking Mechanisms**

**4.13**
We will now give a description of firm agents movements in the worksheets.

**4.14**
Agents use tracking mechanisms to make their movements. For example, a final firm will follow the trace left by a subcontracting firm and when it will be next to the subcontracting firm it will try to form a production chain.

**4.15**
A large number of projects got created using the tracking approach, built as part of the 1998 Artificial Intelligence course at the University of Colorado. The approach is called, also, hill climbing.

**4.16**
In our model, the ground agents activate the tracking mechanisms; they compute the traces left by firm agents. In the following list there is information diffused by the ground agent:

- *cmp_fin*: (final firm's attribute), its diffusion allows subcontracting firms to follow final firms with a specific level of competences;
- *cmp_sub*: (subcontracting firm's attribute), its diffusion allows final firms to follow subcontracting firms with a specific level of competences;
- *fin*: (final firm's attribute), its diffusion allows subcontracting firms to follow any final firm;
- *sub*: (subcontracting firm's attribute), its diffusion allows final firms to follow any subcontracting firm.

Each ground agent computes a average value of the above attributes. For example, indicating with P a generic attribute, the ground computes the values of its 4 neighbors around it. In formula this is expressed as: P = 0.25 × (p[up]+p[down]+p[left]+p[right]).

**4.17**
In this way ground agents process (they compute average values) and store (they retain "p" values) environment information. Now all the principal agents need to do is to follow the increasing value of P towards the objective.

**4.18**
This approach combines "diffusion" and "hill climbing" mechanisms, and allows district agents to move and to interact on the worksheets. In the present model each principal agent tries to reach its objective following the traces of others agents. Final and subcontracting firms follow their objective and can represent, at the same time, an objective for other agents.

**Behavior rules**

**4.19**
We illustrated that firms strategies depends on their inner models; at this point, it is necessary to define how agents react to environment information flow and interact among them. This means explicating agent behaviors rules, which allow agents to select improvement strategies and methods to generate chains.

**4.20**
In the following paragraph, we illustrate three examples of behaviors rules, one for each class of firms.

- *Final Firms behavior rule*: the firm main object is to search for a subcontracting firm to generate a chain, with competency levels equal or greater to its levels. This firm will not prefer to invest its economic resources to increase competency level, even if target values were greater than its values ($m_i < M_i$; $p_i < P_i$; $t_i < T_i$). This behavior is due to its low level of risk.
- *Subcontracting Firms behavior rule*: the high level of risk will drive the firm to increment its competencies level until they equal target ones ($m_i = M_i$; $p_i = P_i$; $t_i = T_i$).The firm will generate a chain with any final firms that will select it.
- *Production Chain rule*: the chain will invest its economic resources in competencies improvements. In this way it could be able to reach more profitable markets. In addition, there is a high probability that the chain will be destroyed; this allows chain firms to look for other partners and to generate another more performing chain.

**4.21**
The content and the number of firms behavioral rules depends on the collective memory of the investigated ID. Again, rules considered in our model correspond to quite general and plausible behaviors that can be contextualized to a specific empirical case.

## Hypothesis

**5.1**
The architecture of the multi-agent model was developed in order to represent the complexity connected to evolutionary dynamics and learning processes of industrial districts. The elements that define principal agents' state, communication mechanisms, information flow and environment structure are derived from the ID collective memory. Consequently we argue that collective memory may significantly affect ID performances and overall behavior. More in detail, the hypotheses that we are going to verify through simulation can be synthesized as follow:

- Collective memory has a moderating effect between ID performances and environmental changes; i.e. ID performances in turbulent rather than in stable scenario depends on the contents of collective memory.
- We argue that when the ID collective memory is strongly shared among ID firms, i.e. when most of the firms show homogeneous values in terms of competencies, values, strategies, production routines and resources, the ID risks to close on itself and experiences its inability to adapt to market evolution.
- when the collective memory of the district keeps a certain level of diversity among agents inner models, thus guaranteeing integrity of the district identity, the system evolve, and it is able to learn and innovate.

## Experimental Sets

**6.1**
At this point is necessary to define the experimental sets of the simulation.

**6.2**
Each simulation starts its run with 40 firm agents: 20 final and 20 subcontractors firms and lasts for 180 cycles. At the beginning of the simulation there are not any production chains, they will appear from the interactions between final and subcontracting firms. In our simulation we consider the variation of only one element of the collective memory, that are values.

**6.3**
We assumed that at the beginning of each simulation run, final and subcontracting firms are characterized by the same level of competencies and of economic resources, but they show different values of risk propensity (risk) and opportunism degree (opp). Opp and Risk variables are binomial (see paragraph 4.10) assuming either 0 or 1, where zero values indicates low (L) and one high (H). Thus, each agent assumes values in one of the four quadrants of the following matrix (Table 2):

**Table 2:** Agents' values

| | | |
|---|---|---|
| *Risk* | **H/L** | **H/H** |
| 0.5 | **L/L** | **L/H** |
| | 0.5 | *Opp* |

We define the different starting populations changing the agents' distribution in the four quadrants of the above matrix. The higher is the presence of the agents in one of the four quadrants, the higher will be the degree of cohesion of the collective memory of the population. That is, when agents take the same values of state variables it means that they share the same objectives, values, norms, etc. and they will behave in a similar way.

**6.4**

According to these issue, we name the starting distributions of the populations as *closed*, when at least the 70% of the starting population takes values in one of the four quadrants of the matrix above; in these cases the diversity of the population is low. While, we say that a starting population is *intermediate* when there is a slight prevalence of one type of agent - the diversity of the population being higher.

**6.5**

In this way, we built up two intermediate and four closed starting distributions, which are summarized in Table 3.

**6.6**

Each population has been tested within two environments, which differ for the type of market evolution. The two environments are:

- Stable Market: this means slow changes in market requirements.
- Turbulent Market: this situation indicates quick changes in market requirements.

The different market evolutions are translated in terms of temporal distance (number of cycles) that elapses between two changes of market conditions. In the stable case this distance is constant during simulation (20 cycle), while in turbulent case it is variable.

**6.7**

In this way we built up 12 experimental set (6 distributions × 2 environments). With these experimental sets we analyzed if the distributions perform in the same way in both environments or not, and if there is any best performer distribution.

**Starting Population Distributions**

I. Intermediate

| | | |
|---|---|---|
| *Risk* | | |
| 0.5 | | **40%** |
| | 0.5 | *Opp* |

II. Intermediate

| | | |
|---|---|---|
| *Risk* | **40%** | |
| 0.5 | | |
| | 0.5 | *Opp* |

III. Closed

| | | |
|---|---|---|
| *Risk* | | |
| 0.5 | | **70%** |
| | 0.5 | *Opp* |

IV. Closed

| | | |
|---|---|---|
| *Risk* | **70%** | |
| 0.5 | | |
| | 0.5 | *Opp* |

V. Closed

| | | |
|---|---|---|
| *Risk* | | |
| 0.5 | **70%** | |
| | 0.5 | *Opp* |

VI. Closed

| | | |
|---|---|---|
| *Risk* | | **70%** |
| 0.5 | | |
| | 0.5 | *Opp* |

**Table 3**. Starting Populations. The percentages indicate the portion of agents that take value in that quadrant

## Results: analysis and discussion

**7.1**

We performed 50 runs per experimental set (multiple-simulation), in order to reduce the influence of agents starting position on the results. Each run was composed of 180 cycles. To measure the performances of the virtual industrial district and to compare the outcomes we introduced two variables:

- P: representing the overall economic performance of the district. It is computed as the sum of the budget of the firms (final, subcontracting and production chains) at each simulation cycle.
- N: number of living firms (final, subcontracting and production chains) at each simulation cycle.

**7.2**

To make our analysis and comparisons we used the final value of these variables, which is the value computed at the $180^{th}$ cycle.

**7.3**

For each multiple-simulations we obtained 50 pairs of values for P and N. At first, the 50 pairs were ordered according to increasing P. Secondly, we drew the 50 pairs on orthogonal axis (see results in Figure 4). Then for each of the experimental sets we performed the analysis of relative frequencies (Table 6), we computed the average for the two variable P and N (Table 4). Finally, we compared the results.

**Table 4:** Average values for N and P on the 50 runs

| **Environment** | **Stable Case** | | **Turbulent Case** | |
|---|---|---|---|---|
| Experimental Set | N | P | N | P |
| I - Intermediate | 11.96 | 79.25 | 7.40 | 31.03 |
| II - Intermediate | 11.66 | 79.78 | 8.20 | 40.42 |
| III - Closed | 11.34 | 66.86 | 6.42 | 19.10 |
| IV- Closed | 10.94 | 88.57 | 6.98 | 33.63 |

7.4

According to Table 3, the first and the third experimental sets are characterized by high opportunism and low risk. We name these last two set as "Low cooperative Districts (LCD)". On the contrary, we called the second and the fourth sets, which are characterized by high levels of risk and low opportunity, "High Cooperative Districts (HCD)". Through the analysis of Table 5, we compared the behaviors of these two types of districts.

| Environment \ Population | | Intermediate N | Intermediate P | | Closed N | Closed P |
|---|---|---|---|---|---|---|
| Stable | *LCD* | 11.96 | 79.25 | *LCD* | 11.34 | 66.86 |
| | *HCD* | 11.66 | 79.78 | *HCD* | 10.94 | 88.57 |
| Turbulent | *LCD* | 7.40 | 31.03 | *LCD* | 6.42 | 19.10 |
| | *HCD* | 8.20 | 40.42 | *HCD* | 6.98 | 33.63 |

**Table 5**. Comparison between HCD and LCD results

7.5

Analyzing the table above, we can provide some considerations:

- Low cooperative Districts: moving from closed to intermediate population distributions, higher diversity rewards more in the turbulent case.
- High cooperative Districts: moving from closed to the intermediate population distributions, higher diversity rewards only in the turbulent case.
- Moving from closed to intermediate population distributions, which means increasing the diversity of the starting population, the highest performance increment is computed for Low cooperative Districts in the turbulent case.
- In turbulent cases an increase in diversity is always rewarded with an increase in performances.

7.6

The simulations within various experimental sets have been used to verify the hypotheses of this research work. The results' analysis have explained some indications on firms' networks evolution.

7.7

The first hypothesis of this work (Collective memory has a moderating effect between ID performances and environmental changes) is confirmed by the simulation experiments carried out. Considering the two competitive scenarios introduced (stable or turbulent) we proved that ID's performances depend on the contents of the collective memory, translated in different sample populations. Of course, one has to keep into account that this result has been obtained by considering only a limited number (2) and certain kind of values.

7.8

In addition, the second and third hypothesis have been partially confirmed by the simulation experiments. Comparing the results of intermediate and closed populations, we verify that the intermediate populations have, in general, higher performances than closed ones (the N and P values), but, in stable cases, this difference is not substantial. In particular, in stable cases the diversity for High Cooperative Districts does not imply an increasing of performances, but, on the contrary, it produces worse economic performances (P values).

7.9

At this point, it is better to be very careful in generalizing conclusions on the role of the district's collective memory, especially because the computational model is at its early stage and suffers of some imperfections. In Complex Adaptive Systems, as IDs, various elements - of political, environmental, and social nature - can effect their dynamics and evolutions.

**Table 6:** Frequency Analysis of the results of the fifty runs performed for each experimental set

| **Segments based on P** | | **Experimental Set I - Stable Case** | | **Experimental Set I - Turbulent Case** | |
|---|---|---|---|---|---|
| Min | max | Frequency | Relative Fr. | Frequency | Relative Fr. |
| 0 | 25000 | 0 | 0% | 12 | 24% |
| 25000 | 50000 | 4 | 8% | 38 | 76% |
| 50000 | 75000 | 18 | 36% | 0 | 0% |
| >75000 | | 28 | 56% | 0 | 0% |
| **Segments based on P** | | **Experimental Set II - Stable Case** | | **Experimental Set II - Turbulent Case** | |
| Min | max | Frequency | Relative Fr. | Frequency | Relative Fr. |
| 0 | 25000 | 0 | 0% | 19 | 38% |
| 25000 | 50000 | 3 | 6% | 27 | 54% |
| 50000 | 75000 | 17 | 34% | 3 | 6% |
| >75000 | | 30 | 60% | 1 | 2% |
| **Segments based on P** | | **Experimental Set III - Stable Case** | | **Experimental Set III - Turbulent Case** | |
| Min | max | Frequency | Relative Fr. | Frequency | Relative Fr. |
| 0 | 25000 | 0 | 0% | 6 | 12% |
| 25000 | 50000 | 3 | 6% | 32 | 64% |
| 50000 | 75000 | 17 | 34% | 12 | 24% |
| >75000 | | 30 | 60% | 0 | 0% |
| **Segments based on P** | | **Experimental Set IV - Stable Case** | | **Experimental Set IV - Turbulent Case** | |
| Min | max | Frequency | Relative Fr. | Frequency | Relative Fr. |
| 0 | 25000 | 0 | 0% | 35 | 70% |
| 25000 | 50000 | 9 | 18% | 15 | 30% |
| 50000 | 75000 | 23 | 46% | 0 | 0% |
| >75000 | | 18 | 36% | 0 | 0% |
| **Segments based on P** | | **Experimental Set V - Stable Case** | | **Experimental Set V - Turbulent Case** | |
| Min | max | Frequency | Relative Fr. | Frequency | Relative Fr. |
| 0 | 25000 | 0 | 0% | 9 | 18% |
| 25000 | 50000 | 2 | 4% | 37 | 74% |
| 50000 | 75000 | 9 | 18% | 4 | 8% |
| >75000 | | 39 | 78% | 0 | 0% |

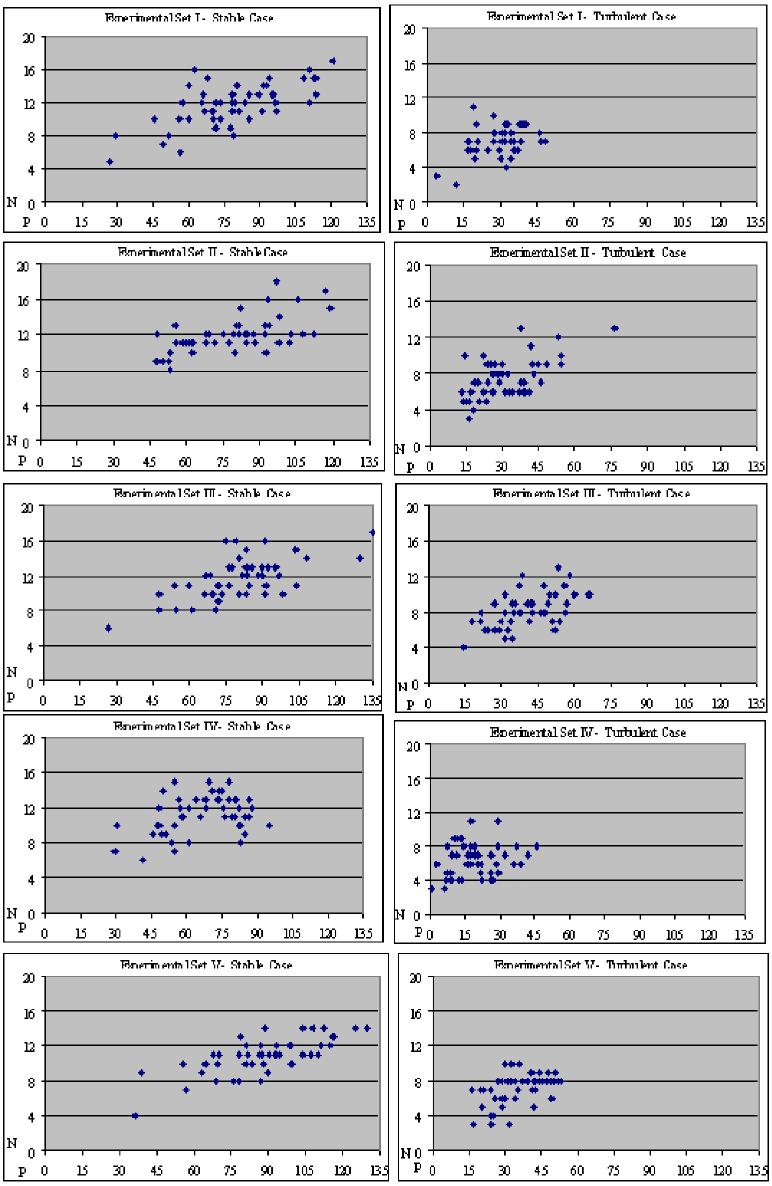

**Figure 4**. Graphical representation of the results of the fifty runs performed for each experimental set

## Conclusions

**8.1**

The proposed simulative model permits to develop a set of computational experiments to investigate how district's collective memory influences firms' performance, according to different characteristics of the market (turbulent or stable).

**8.2**

This simulation model is structured on a quite simple firm-agent model. The model is still at its early stage of deployment, principal agents follow standard schema of behaviour, more than a cognitive model, which are based on environment's characteristics and interaction rules (Squazzoni 2001).

**8.3**

It is clear that the developed simulation model suffers from some imperfections and simplifications and it should be seen as a trial run to analyze the influence of collective memory's mechanisms and processes on IDs performances.

**8.4**

In the following list, we make some observations that the readers could raise analyzing the elements and mechanisms of the simulation model presented:

- We test the effects of two elements of the collective memory - risk propensity and opportunism degree - in different IDs' environments (stable/turbulent). We recognize this is a simplification of the mechanisms and processes regulating the degree of cohesion of the district collective memory. But, this exercise helped us in evaluating how ID's performances are impacted also by small variations. The simulations' results show that in some cases (see the results higher competitive districts) the impacts of collective memory's mechanisms is not predictable.
- The analysis of the impacts of the elements described in the simulation model is not exhaustive. Our intention is to test the other elements introduced in the model. As

example, we will test different types of diffusion processes, which means facilitate or stop the communication mechanisms among district firms. Nevertheless, without a complete analysis of the impacts of all elements of the collective memory on IDs' performances it will be hard to go on for further developments;
- A crucial element is the market demand. Many questions related to market demand are not included in the presented model.
- We assumed that final firms are completely able to identify market requests and to transfer these information to subcontracting firms, through the generation of production chains. Thus, we imply that there are not any communication errors between:
  - the market and final firms;
  - final firms and subcontracting firms;
  - production chains and market.

  The second type of errors was partially included in the model; we introduced some costs that the production chains have to invest to remove communication errors between firms. Concerning the market demand, we didn't introduce nor costs neither mechanisms which take into account these errors. In our model final firms didn't make any errors in acquiring market's requirements. Nor the market (the clients) make any error in evaluating production chains' outcomes. We recognise this is not a real situation; for example clients may use different evaluation processes when buying. As a consequence, production chains could receive wrong feedbacks from the market. At this stage of the model, the impacts relative to market errors weren't considered mainly because they imply a further complication for the mechanisms and processes which regulate the functioning of the collective memory. But, future developments of the model will involve the effects of communication errors on IDs evolution;
- Another important question is the number of districts' firms acting in the simulation model. This variable was treated as exogenous. In our simulations, there is a fixed number of firms (20 final and 20 subcontracting firms) at the beginning of the simulations. These firms evolve during the simulation and may die for the lack of economic resources Thus, there are some mechanisms that affect the decrease of the number of firms, but there are not any mechanisms which control the introduction of new firms in the virtual district. This represents a lack for our model, because the emerging of new firms in the competitive scenario (as the disappearing of existing ones) is an important element in competitive processes. But, it's important to highlight that in our analysis' results we compare always final data (the values of P and N at the 180° cycle) of different competitive scenarios which evolved through the same mechanisms.

**8.5**

The issues illustrated above are important for two reasons: firstly to highlight the consciousness of the authors about the limitations of the simulative model and secondly this list will be used as guide lines for future improvements of the model.

**8.6**

According to these issues, next developments of the model will be focused on two main aspects:

- the improvement of firms agents behaviours with more cognitive-evolving aspects, which should allow firms to evaluate the competitive level of the district (in order to regulate the emerging of new firms, to better select improvement strategies and so on);
- the introduction of new models of interactions and collaborations among firms.

Even if the proposed model is quite simple, on the other side we want to highlight its generality and flexibility. In fact, it is possible to use our model to make simulative experiments for any kind of ID and firm network. The fundamental step is the characterizations of the elements of our simulative model into specific features of the ID in exam.

**8.7**

Thus, the whole model works only if we have a good tool - an investigation protocol - to collect data from real IDs. Thus, we are building up an investigation protocol which, applied to a real ID - through surveys, interviews and data collection - will help us to understand the peculiarities of an ID and to translate these peculiarities into the elements (variables, competencies, strategies, communication mechanisms, etc.) of the collective model defined in the simulation model.

**8.8**

The investigation protocol would be used, in real ID, also to acquire others elements of the collective memory and to improve the ones already defined. Moreover, the investigation protocol should allow us to understand how the collective memory changes and evolves during time. This task will advice us in the definition of new elements of the collective memory and to verify those already described.

---

## Note

Although the paper is the result of common work, in this version §3.3 is by G. Zollo, §3.1, §3.2 and §6 by L. Iandoli, §2 and §4.1 by C. Ponsiglione, §4.2, §4.3 and §4.4 by F. Borrelli. The remaining sections are written jointly by the authors.

---

## References


ARTHUR W.B., Durlauf S.N., Lane D.A. (eds) (1997) *The Economy as an Evolving Complex System II*, Redwood (CA), Addison-Wesley Longman.

AYDALOT P. (ed. by) (1986) *Milieux Innovateurs en Europe - Innovative Environments in Europe, Paris*, Université de Paris I Sorbonne, GREMI - Groupement de Recherche sur les Milieux Innovateurs en Europe.

BECATTINI G. (1979) "Dal settore industriale al distretto industriale. Alcune considerazioni sull'unità di indagine dell'economia industriale", *L'Industria*, n. 1.

BECATTINI G. (1989) "Riflessioni sul distretto industriale marshalliano come concetto socio economico", *Stato e Mercato*, n. 25, pp. 111-128.

BECATTINI G. (2000) "Le vie del cambiamento", in Becattini G., *Il distretto industriale*, Torino, Rosenberg & Sellier, pp. 117-132.

BERGER P.L., Luckmann T. (1966) *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*, New York, Doubleday .

BOERO R., Squazzoni F. (2001) "A computational prototype of industrial district", *Workshop on "Complexity and Industrial Districts",* Università di Modena e Reggio Emilia.

BRUSCO S. (1982) "The Emilian Model: Productive decentralisation and social integration", *Cambridge Journal of Economics*, vol. 6, pp. 167-184.

CAMAGNI R. (1989) "Cambiamento tecnologico, milieu locale e reti d'imprese: verso una teoria dinamica dello spazio economico", *Economia e Politica Industriale*, n.64, pp. 209-236.

CAMAGNI R. (1991) "Local milieu, uncertainty and innovation networks: towards a new dynamic theory of economic space", in Camagni R. (ed. by), *Innovation networks: spatial perspective*s, London, Belhaven Press.

COASE R. (1937) "The Nature of the Firms", *Economica,* vol. 4(16), pp. 386-405.

CONTE, R. (1999) "Social Intelligence Among Autonomous Agents". *Journal of Computational & Mathematical Organization Theory* 5(3), 203-228.

CREVOISIER O., Maillat D., Vasserot J.Y. (1989) "L'apport du milieu dans le processus d'innovation", in Maillat D., Perrin J. (eds), *Entreprises innovatrice et reseaux locaux* , Paris, Universit. de Paris I Sorbonne, GREMI - Groupement de Recherche sur les Milieux Innovateurs en Europe.

De ROSA M., Turri E. (2002) "L'analisi territoriale tra riduzionismo ed esaustività:modelli teorici e strumenti empirici", Convegno 'Storicità e Attualità della Scuola Economico-Agraria Italiana: Il pensiero di Mario Bandini', Università di Perugia, Facoltà di Agraria, 12 Dicembre.

Fransman M. (1994) "Information, Knowledge, Vision and Theories of the Firm", *Industrial and Corporate Change* 3 (2), pp: 1-45.

FUÀ G., Zacchia C. (1983) *Industrializzazione senza fratture*, Bologna, Il Mulino.

GAROFOLI G. (ed. by) (1978) *Ristrutturazione industriale e territorio*, Milano, Franco Angeli.

GRANOVETTER M. (1985) "Economic Action and Social Structure: The problem of embedded-ness", *American Journal of Sociology*, vol. 91(3), pp. 481-510.

GRANT R.M. (1996) "Toward a Knowledge-Based Theory of the Firm", *Strategic Management Journal*, Vol 17: pp.109-122.

HERRIOT, S.R., Levinthal, D, March, J.G. (1975) "Learning from Experience in Organizations", *American Economic Review,* 75, pp: 298 - 302.

MARSHALL A. (1919) *Industry and Trade*, London, MacMillan.

NELSON R.R., Winter S.G. (1982) *An Evolutionary Theory of Economic Change*, Cambridge (MA), The Belknap Press of Harvard University Press.

PÉLI G., Nooteboom B. (1997) "Simulation of Learning in Supply Partnership", *Computational & Mathematical Organization Theory*, vol. 3(1), pp. 43-66.

PENROSE E.T. (1959) *The Theory of the Growth of the Firm*, Oxford, Basil Blackwell.

PIORE M.J., Sabel C.F. (1984) *The Second Industrial Divide: Possibilities for Prosperity*, New York, Basic Books.

POWELL W.W. (1991) "Expanding the Scope of Institutional Analysis", in Powell W.W., Di Maggio P.J. (eds), *The New Institutionalism in Organisational Analysis*, Chicago, The

University of Chicago Press, pp. 183-203.

RATTI R., D'Ambrogio F. (1989) "Processus d'innovation et integration au milieu local", in Maillat D., Perrin J. (eds), *Entreprises innovatrice et reseaux locaux*, Paris, Università de Paris I Sorbonne, GREMI - Groupement de Recherche sur les Milieux Innovateurs en Europe.

REPENNING A., Ioannidou A., Zola J. (2000) "AgentSheets: End User Programmable Simulations". *Journal of Artificial Societies and Social Simulation*, vol.3, no.3. http://jasss.soc.surrey.ac.uk/3/3/forum/1.html

RULLANI E. (1989) "Economia delle reti: i linguaggi come mezzi di produzione", *Economia e Politica Industriale*, n. 64, pp.125-164.

RULLANI E. (1992) "Divisione del lavoro e reti di impresa: il governo della Complessità", in Belussi F., (a cura di), *Nuovi Modelli D'Impresa, Gerarchie Organizzative e Imprese Rete,* Milano, Franco Angeli, pp. 139-194.

Rullani E. (2002) "Il distretto industriale come sistema adattivo complesso", in Quadrio Curzio A., Fortis M. (a cura di), *Complessità e Distretti Industriali*, Bologna, Il Mulino.

SABA A. (1995) *Il modello italiano. La "specializzazione flessibile" e i distretti industriali*, FrancoAngeli, Milano.

SAKO M. (1992) "La cooperazione competitive: il sistema giapponese e lo sviluppo delle relazioni inter-impresa", in Belussi F. (a cura di), *Nuovi Modelli D'Impresa, Gerarchie Organizzative e Imprese Rete,* Milano, Franco Angeli, pp. 239-257.

SCHEIN E. (1985) *Organizational Culture and Leadership*, San Francisco, Jossey Bass.

SCHUMPETER J. A. (1934) *The Theory of Economic Development*, Nova York, Oxford University Press.

SCOTT W.R. (1995) *Institutions and Organizations, Foundations for Organizational Science*, Thousand Oaks (CA), Sage Publications.

SIMON H.A. (1961) *Administrative Behavior*, 2nd edition, New York, John Wiley & Son

SQUAZZONI F. (2001) *Simulazione di un prototipo di distretto industriale. Un modello computazionale basato su agenti,* University of Brescia, Doctoral Thesis in Economic Sociology, Cycle XIV.

STRADER T. J., Lin F., Shaw M. J. (1998) "Simulation of Order Fulfillment in Divergent Assembly Supply Chain", *Journal of Artificial Societies and Social Simulation*, vol. 1(2). http://jasss.soc.surrey.ac.uk/1/2/5.html

UZZI B. (1996) "The sources and consequences of embeddedness for the economic performance of organizations", *American Sociological Review,* 61, pp: 674-698.

WALSH J.P., Ungson G.R. (1991) "Organizational Memory", *Academy of Management Review*, vol. 16, n. 1, pp: 57-91.

WILLIAMSON, O. E. (1975) *Markets and Hierarchies: Analysis and Antitrust Implications* New York: The Free Press.

WILLIAMSON, O. E. (1985) *The Economic Institutions of Capitalism*. New York: The Free Press.