Enterprise clusters triggered by radical innovation: a modelistic approach

Marco Pironti, Marco Remondino and Paola Pisano
University of Torino, Torino, Italy

Abstract

Purpose – This papers aims to deal with enterprise networks and clusters dynamics, as well as inter-firm joint efforts and collaborations, in order to study their evolution and possible effects when radical innovation occurs inside them.

Design/methodology/approach – In order to study these dynamics, with the optimal balancing among different strategies and the importance of exogenous parameters in cluster creation, a model is presented. It follows the agent-based paradigm, particularly suited for describing complex social systems in which many parts interact among them. This allows one to create simulations of the studied system, and to test different hypotheses. Besides, it is the only paradigm in which the emergent features of complex systems can arise spontaneously, thanks to the bottom-up design. A model is introduced and described in detail.

Findings – Qualitative results are described, reflecting current state-of-the art theories. The results show how clusters emerge and evolve among enterprises, and how radical innovation can trigger this phenomenon. Different managerial behaviour (externally or internally focused) is discussed as well.

Originality/value – The most important feature of a model based on agent is the possibility of repeating the experiment several times, by changing one or few variables at a time, by leaving the others unchanged. It constitutes for social sciences the equivalent of lab experiments for such disciplines as physics or chemistry. The presented model allows the study of different clustering scenarios, by changing the initial conditions.

Keywords Enterprise zones, Innovation, Diffusion, Management strategy

Paper type Research paper

Introduction

According to Penrose (1959), firm's productive opportunity is defined as the possibilities for deploying resources that its entrepreneurs and managers can see and which they are willing and able to act on. These premises bring firms to face an important strategic dilemma. On the one hand, exploiting existing competencies may provide short-term success, although competence exploration can become a hindrance to the firm's long term viability by stifling the exploration of new competencies and the development new resources (Levinthal and March, 1993). On the other hand, deploying resource combinations as a form of external exploration search inherently mitigates the risk of failure by making the new combination perform in ways that firms in the mainstream market already value, while deploying resource combination as a form of internal exploration may dramatically enlarge the set of all possible deployments that

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are within someone's ability and means to execute, increase the number of productive possibilities, and enable new market application to emerge (Lee and Lee, 2003; Hult *et al.*, 2005).

The growth and development of a firm depend, therefore, on its ability to develop new capabilities and resources and introduce them in the market (Dougherty and Hardy, 1996). Thus, two different types of exploratory behaviours are involved in deploying new resources combination (Nerkar and Roberts, 2004). The first one is internally focused, when firms can explore new resource combinations by using their research and development activities (Teece, 1982). On the other hand, externally focused firms can search along the value chain, using the range of complementary assets that results from participation in the competitive arena (Day, 1999). The effects extend, through network externalities, to others with who the learning organization interacts (Katz and Shapiro, 1986). Reason inhibits foolishness; learning and imitation inhibit experimentation. During external exploration, each firm can reshape its communication and learning ego-network of relationships as result of the decisions to acquire new competencies (Mohrman *et al.*, 2003, Choi *et al.*, 2008). Network change consists of changes in the number of actors (exit and entry), and changes in number and patterns of link information. The network can expand, churn, strengthen or shrink. Each network change is brought about by specific combination of changes in tie creation, tie deletion, and by changes in an actor's portfolio size (number of link) and portfolio range (numbers of partners). Philippen and Riccaboni (2007) in their work on "radical innovation and network evolution" (2007) focus on the importance of local link formation and the process of distant link formation. Regarding the formation of new links, Gulati (1995) finds the process of new tie creation to be heavily embedded in an actors' existing network. This means that new ties are often formed with prior partners or with partners of prior partners, indicating network growth to be a local process. Particularly when considering inter-firm alliances, new link formation is considered risky and actors prefer alliances that are embedded in a dense clique were norms are more likely to be enforceable and opportunistic behaviour to be punished. Distant link formation implies that new linkages are created with partners who are not known to the existing partners of an actor. At the level of the firm, Burt (1982) shows that distant linkages that serve as a bridge between dense local clique of firms, can provide access to new source of information and favourable strategic negotiation position, which improve the firms' position in the network and industry (Tenkasi and Chesmore, 2003).

The main goal of this paper is to introduce a computational model to be used as a tool for studying and analyzing the effects of different managerial behaviour (externally or internally focused) on enterprise clusters and, at the same time, to explore the effects of innovations on the network itself. The internally or externally focused behaviours have a very different impact on the clusters formation, along with a series of parameters included in the model.

Enterprise and business clusters

Clustering is definable as the tendency of vertically and/or horizontally integrated firms in related lines of business to concentrate geographically, or, to a more general extent, virtually (Carrie, 2000).

Cluster policies are an example of pro-active industrial policy with shared responsibilities among actors; besides, the agglomeration of firms and their suppliers can confer competitive advantage to the enterprises involved.

There are many social and economic reasons leading to clusters creation. The main economic drivers of cluster formation in particular industries include:

- *Proximity to markets*. Despite low-cost international transportation, being near to markets can be important in cluster development (products that are not easy to transport, that require continuous interaction with customers).
- *Supplies of specialised labour*. The existence of specialised pools of labour, such as occur around many universities.
- *Presence of input and equipment suppliers*. A high frequency of exchanges between co-located capital goods producers and users.
- *Availability of specific natural resources.*
- *Economies of scale in production*. Such economies may allow only a small number of efficient-scale plants in a given market.
- *Availability of infrastructure*. Some types of infrastructure may also be quite specific, such as with certain transport or tourist facilities, further encouraging agglomeration.
- *Low transaction costs*. When firms and their suppliers operate near to each other, and the frequency of interaction is high, the costs of negotiation and contract enforcement may be reduced (Dijk and Sverrisson, 2003).

As a consequence, there is an improvement of information access. This is straightforward: when many enterprises are integrated, than the information system is usually shared or, if individually managed, it allows an easier communication among them. Enterprises, when aggregated in clusters, can share, for example: product and market information, product design, marketing policies, training, recruitment services, human resources, skills, purchasing (lower prices for raw material and supplies), transportation and delivery (for geographical clusters), quality control, testing facilities, financing (credit guarantees at collective level), sponsorships (Zhang and Li, 2008). Many of the mentioned can be considered as "competences". That's why the model takes as its basic unit for link creation the generic "competence exchange" among two enterprises. Of course this is true during the external exploration phase, where an enterprise is looking for the best partner to create a new link, or to strengthen an existing one. Though, also the internal exploration is very important since it can allow an enterprise to develop a new competence, that will be used later on to be exchanged, thus constituting a new link with another firm (Martinez and Sanchez, 2008).

The price-independent preferences of both the market and its participants are based on each ones perception of the other rather than the market simply being the sum of all its participants actions as is usually the case. So, the cluster effect is a usually cited example of emergence.

Innovation diffusion

To analyze network dynamics, we study possible effects of innovation inside enterprise clusters. Innovation can be defined depending on what its being innovated (process, product, or service) and the intrinsic characteristics of innovation itself, like radical incremental, discontinuous, imitative, architectural, modular, improving, evolutionary and so on. In this article we consider only radical innovation for the huge impact and the easiness of traceability and tractability in the context of network topology.

Kelley (2009), starting from Leifer *et al.* (2000), defines radical innovation as the one involving the commercialization of products based on significant leaps in technology development, with the potential for entirely new features or order of magnitude improvements in performance or cost compared with existing substitutes. While developing innovation strategies, managers must balance the desire for strategic clarity with the need of creativity and exploration. They must structure programs that ensure innovations benefits from the organization's resources while minimizing the numerous constraints that can prevent these unconventional activities. Additionally, managers must also ensure that these factors do not restrict the flexibility required for successful innovation, though they may favor management processes that provide accountability and effective resource allocation.

Radical innovation has been defined as the innovation that embodies a new technology that results in a new market infrastructure. The introduction of radical innovation results in discontinuities on both macro and micro level. Industry or market level will automatically cause discontinuities in the firm and customer level: if a new industry results from radical innovation, new firms and new customers also emerge for that innovation. Radical innovations often do not address a recognized demand but create a demand previously unrecognized by consumer (Garcia and Calantone, 2002).

The social interactions that firms have with clients, providers, research institutes, and so on, constitute the social capital that allows firms to achieve greater innovation capacities (Landry *et al.*, 2007). Referring to radical innovation, the importance of social capital[1] can explain why some authors have stressed the importance of learning from social network concepts and theories in order to deepen the knowledge exchange between firms (Landry and Amara, 2003; Angel, 2002; Beckman and Haunschild, 2002).

In order to study these dynamics, as long as the optimal balancing among different strategies and the importance of exogenous parameters in cluster creation, a model is presented. It follows the agent-based paradigm, particularly suited for describing complex social systems in which many parts interact among them. This allows to create simulations of the studied system, and to test different hypotheses. Besides, it is the only paradigm in which the emergent features of complex systems can arise spontaneously, thanks to the bottom-up design.

Agent-based simulation

Why do enterprises team up? There can be many reasons for this strategy, leading, in its widest extent, to the creation of joint-ventures, i.e. a new economical subject formed by two or more enterprises with the goal of new projects, or of clusters and networks of enterprises. The leading cause for these phenomena is the optimization of the production, by resources and competences sharing. Agent based simulation is an effective paradigm for studying complex systems. It allows the creation of virtual societies, in which each agent can interact with others basing on certain rules. The agents are basic entities, endowed with the capacity of performing certain actions, and with certain variables defining their state. In the model presented here, the agents are reactive, meaning that they simply react to the stimuli coming from the environment and from other agents, without elaborating their own strategies. When the model is formally built and implemented, it can be run by changing a parameter at a time, and emergence of a complex behaviour occurs.

Agent-based modelling is thus one of most interesting and advanced approaches for simulating a complex system: in a social context, the single parts and the whole are often very hard to describe in detail. Besides, there are agent-based formalisms, which allow studying the emergence of social behaviour through the creation and study of models, known as artificial societies. Thanks to the ever-increasing computational power, it has been possible to use such models to create software, based on intelligent agents, whose aggregate behaviour is complex and difficult to predict, and which can be used in open and distributed systems.

In Franklin and Graesser (1997) we read that: "An autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future".

Another very general, yet comprehensive definition is provided by Jennings (1996): ". . . the term (agent) is usually applied to describe self-contained programs which can control their own actions based on their perceptions of their operating environment".

Agents have traditionally been categorized as one of the following types (Woolridge and Jennings, 1995):

(1) Reactive.

(2) Collaborative/deliberative.

(3) Hybrid.

When designing any agent-based system, it is important to determine how sophisticated the agents' reasoning will be. Reactive agents simply retrieve pre-set behaviours similar to reflexes, without maintaining any internal state. On the other hand, deliberative agents behave more like they are thinking, by searching through a space of behaviours, maintaining internal state, and predicting the effect of actions. Although the line between reactive and deliberative agents can be somewhat blurry, an agent with no internal state is certainly reactive, and one that bases its actions on the predicted actions of other agents is deliberative.

The agents used in this paper are reactive, but organized in the form of a MAS (Multi Agent System), which can be thought of as a group of interacting agents working together or communicating among each other. To maximize the efficiency of the system, each agent must be able to reason about other agents' actions in addition to its own. A dynamic and unpredictable environment creates a need for an agent to employ flexible strategies. The more flexible the strategies however, the more difficult it becomes to predict what the other agents are going to do. For this reason, coordination mechanisms have been developed to help the agents interact when performing complex actions requiring teamwork. These mechanisms must ensure that the plans of individual agents do not conflict, while guiding the agents in pursuit of the system goals. Many simulation paradigms exist; agent-based simulation is probably the one that best captures the human factor behind decisions. This is because the model is not organized with explicit equations, but is made up of many different entities with their own behaviour. The macro results emerge naturally through the interaction of these micro behaviours and are often more than the algebraic sum of them. This is why this paradigm is optimal for the purposes of modelling complex systems and of capturing the human factor. The model presented in this paper strictly follows the agent-based paradigm and employs reactive agents, as detailed in the following paragraph.

The model

The model is built in Java, thus following the object oriented philosophy (Barclay and Savage, 2004) and has been engineered and built at the E-business L@B, University of Turin. This is suitable for agent based modelling, since the individual agents can be seen as objects coming from a prototypal class, interacting among them basing on the internal rules (methods). While the reactive nature of the agents may seem a limitation, it's indeed a way to keep track of the aggregate behaviour of a large number of entities acting in the same system at the same time. All the numerical parameters can be decided at the beginning of each simulation (e.g. number of enterprises, and so on). Everything in the model is seen as an agent; thus we have three kinds of agents: Environment, Enterprises and Emissaries (E^3). This is done since each of them, even the environment, is endowed with some actions to perform.

Heat metaphor

In order to represent the advantage of an enterprise in owning different competences, the "heat" metaphor is introduced. In agent-based models for Economics, the metaphor-based approach (Remondino, 2003) is an established way of representing real phenomena through computational and physical metaphors. In this case, a quantum of heat is assigned for each competence at each simulation turn. If the competence is internal (i.e. developed by the enterprise) this value is higher. If the competence is external (i.e. borrowed from another enterprise) this value is lower. This is realistic, since in the model we do not have any form of variable cost for competencies, and thus an internal competence is rewarded more. Heat is thus a metaphor not only for the profit that an enterprise can derive from owning many competences, but also for the managing and synergic part (e.g. economy of scale).

Heat is also expendable in the process of creating new internal competences (exploitation) and of looking for partner with who to share them in exchange of external competences (exploration). At each time-step, a part of the heat is scattered (this can be regarded as a set of costs for the enterprise). If the individual heat gets under a threshold, the enterprise ceases its activity and disappears from the environment.

At an aggregate level, average environmental heat is a good and synthetic measure to monitor the state of the system.

Environment

This is a meta-agent, representing the environment in which the proper agents act. It is considered an agent itself, since it can perform some actions on the others and on the heat. If features the following properties: a grid (X, Y), i.e. a lattice in the form of a matrix, containing cells; a dispersion value, i.e. a real number used to calculate the dissipated heat at each step; the heat threshold under which an enterprise ceases; a value defining the infrastructure level and quality; a threshold over which new enterprises are introduced; a function polling the average heat (of the whole grid). The environment affects the heat dispersion over the grid and, based on the parameter described previously, allows new enterprises to join the world.

Enterprise

This is the most important and central type of agent in the model. Its behaviour is based on the reactive paradigm, i.e. stimulus-reaction. The goal for these agents is that of surviving in the environment (i.e. never go under the minimum allowed heat threshold). They are endowed with a heat level (energy) that will be consumed when performing actions. They feature a unique ID, a coordinate system (to track their position on the lattice), and a real number identifying the heat they own. The most important feature of the enterprise agent is a matrix identifying which competences (processes) it can dispose of. In the first row, each position of the vector identifies a specific competence, and is equal to 1, if disposed of, or to 0 if lacking. A second row is used to identify internal competences or outsourced ones (in that case, the ID of the lender is memorized). A third row is used to store a value to identify the owned competences developed after a phase of internal exploration, to distinguish them from those possessed from the beginning. Besides, an enterprise can be "settled", or "not settled", meaning that it joined the world, but is still looking for the best position on the territory through its emissary. The enterprise features a wired original behaviour: internally or externally explorative. This is the default behaviour, the one with which an enterprise is born, but it can be changed under certain circumstances. This means that an enterprise can be naturally oriented to internal explorative strategy (preferring to develop new processes internally), but can act the opposite way, if it considers it can be more convenient. Of course, the externally explorative enterprises have a different bias from internally explorative ones, when deciding what strategy to actually take.

Finally, the enterprise keeps track of its collaborators (i.e. the list of enterprise with who it is exchanging competencies and making synergies) and has a parameter defining the minimum number of competencies it expects to find, in order to form a joint. The main goal for each enterprise is that of acquiring competences, both through internal (e.g. research and development) and external exploration (e.g. forming new links with other enterprises). The enterprises are rewarded with heat based on the number of competences they possess (different, parameterized weights for internal or external ones), which is spread in the surrounding territory, thus slowly evaporating, and is used for internal and external exploration tasks.

Emissary

These are agents that strictly belong to the enterprises, and are to be seen as probes able to move on the territory and detect information about it. They are used in two different situations:

(1) If the enterprise is not settled yet (just appeared on the territory), it is sent out to find the best place to settle.

(2) If the enterprise is settled and chooses to explore externally, an emissary is sent out to find the best possible partners.

In both cases, the emissary, that has a field of vision limited to the surrounding eight cells, probes the territory for heat and moves following the hottest cells. When it finds an enterprise in a cell, it probes its competencies and compares them to those possessed by its chief enterprise verifying if these are a good complement (according to the parameter described in the previous section). In the first case, the enterprise is settled in a cell, which is near the best enterprise found during the movement. In the second case, the enterprise asks the best found for collaboration).

While moving, the emissary consumes a quantum of heat, which is directly dependant on the quality of infrastructures of the environment.

The movement of the emissaries is detailed within the following section.

In the following paragraph a formal insight of the model is given through a set of defining equations, for the agents and the general rules.

Model equations

In order to formally describe the model, a set of equations is described in the following.

The multi agent system at time T is defined as:

$$MAS_T = \langle \bar{E},\ \bar{e},\ \bar{\varepsilon},\ \overline{link} \rangle. \tag{1}$$

where $\bar{E}$ represents the environment and is formed by a grid n^*m, and a set $\bar{k}$:

$$\begin{cases} E =< n^*m,\ \bar{k} > \\ \quad n,\ m > 0 \end{cases} \tag{2}$$

where the set $\bar{k}$ defines the heat for each cell, $\bar{e}$ is the set of enterprises with coordinates on the grid, and $\bar{\varepsilon}$ is the set of the emissaries, also scattered on the grid:

$$\begin{cases} \bar{k} =< k_{i,j} > \\ \bar{e} =< e_{i',j'} > \\ \bar{\varepsilon} =< \varepsilon_{i'',j''} > \\ 0 <\ i,\ i', i'' \leq n \\ 0 < j, j', j'' \leq m. \end{cases} \tag{3}$$

Each enterprise is composed by a vector $\vec{c}$, and an emissary (ε_e). The vector c defines the owned competences, with a length L and competences c_1 represented by a Boolean variable (where 1 means that the ℓ^{th} competence is owned, while 0 means that it is lacking):

$$\begin{cases} e_{ij} \in \vec{c}_i \varepsilon_\theta \\ \vec{c} = (L_i, C_1) \\ = \leq 1 \leq L \\ C_1 = \text{Boolean}. \end{cases} \tag{4}$$

In $T = t > 0$, k_{ij}, that is the heat of each cell on the grid, depends on the heat produced by the enterprises (K_e) and the dispersion effect d). The heat of each enterprise is function of the competences it possesses and of the behavior it carried on in the last turns (b_e):

$$\begin{cases} k_{i,j} = [f(K]_e, d) \\ K_e = f\left(\vec{c}_e, b_e\right) \\ b \in \bar{b} \\ \bar{b} =< \text{set of behaviours} > . \end{cases} \tag{5}$$

In particular, a certain behavior can be successful, meaning that at the end of a phase of internal or external exploration, a new competence (internal or outsourced, respectively) will be possessed. Otherwise, a it is unsuccessful when, after some steps of research and development (internal exploration) or external market research to find a partner, nothing new is found, and thus the ℓ^{th} competence remains zero:

$$\begin{cases} \begin{cases} \text{if } (b = \text{success}) \text{ then } C_1 = 1 \\ \text{else } C_1 = 0 \end{cases} \\ b \in \bar{b} \end{cases} \tag{6}$$

At each time-step the set of links (connecting two enterprises together) is updated basing on the competences of the enterprises:

$$\begin{cases} \overline{link} =< link\left(e_{i,j,}e_{i',j'}\right) > \\ link(e_{i,j,}e_{i',j'}) = f\left(e_{\underline{i,l}j}e_{\underline{l'j'}}\right) \end{cases} \tag{7}$$

Specifically, when an enterprise does external exploration, it looks for a good partner, i.e. an enterprise with a number of competences to share. So, if an enterprise with a vector like 10001 meets one with a vector like 01110 then there is a perfect match and the two enterprises will create a link among them, to share the reciprocally missing competences. This is the perfect situation, but not the only one in which two enterprises can create a link; in fact, it is enough that there is at least one competence to reciprocally share. The strength of the link is directly proportional to the exchanged competences. This set of equations and rules is enough to explore the effects on the network of the behaviors of the enterprises, namely the way in which the firms are managed (externally or internally focused). Though the model allows exploration of the effects on innovation (i.e. a competence that is possessed only by one enterprise).

In $T = t > t$ a radical innovation can be metaphorically introduced in the system (this is called "shock mode", since this is decided by the user, at an arbitrary step) by means of increasing the length of the vector of competences of a specific enterprise:

$$\begin{cases} L \leftarrow L + 1 \\ C_{l+1}(e) = 1 \\ C_{l+1}(\bar{e} - e) = 0 \end{cases} \quad (8)$$

Meaning that the competence C_{l+1} will be possessed by only one enterprise, at that time, while the same competence will be lacking to all the others; though, all the enterprises' vectors will increase in length, meaning that potentially all of them will be able to internally develop that new competence through R&D, from then on.

The vector length metaphorically represents the complexity of the sector (industry) in which the enterprises operate; an highly technological sector has many more potential competences than a non-technological one. So, another kind of "shock effect" to the system is that of increasing the length of the vector by more than one component, and by leaving all the new components to zero for all the enterprises. In this way, they will have to develop themselves the new competences by means of internal exploration. The analysis phase is carried on after several steps after t, in order to see how the introduction of the innovation impacted the network and the enterprise in which the innovation was first introduced. So we have an analysis phase in $T = t > t$ defined as:

$$\begin{cases} MAS_t^{'} \text{vs} \, MAS_t^{''} \\ I \rightarrow d\theta link: d\theta e; d\theta k. \end{cases} \quad (9)$$

Namely, the comparison among the system at time t' and the same system at time t'', since the innovation has differential effects on the number (and nature) of the links, on the number of enterprises and the heat of the cells composing the environment, always depending on the managerial behavior of the involved enterprises. At the beginning of a simulation, the user can change the core parameters, in order to create a particular scenario to study and analyze.

Synthetic model iterations

At step 0, a lattice is created (n, m). A number of enterprises (X) are created (according to the proper parameter set by the user), x of them internally explorative (*IE*) and X-x of them externally explorative (*EE*). X, x, n, and m are set by the user, before the simulation starts.

At step 1, the environment checks if some enterprise reached the minimum heat threshold; if so, removes it from the world. After that, each enterprise, if idle (not doing anything) decides what behavior to follow.

At step 2, all the enterprises that selected to be *EE* move their emissary by one cell. All the *IE* ones work on the R&D cycle (one step at a time). At step 3, the *EE* enterprises check if the emissary finished its energy and, in that case, ask the best-found enterprise for collaboration (they can receive a positive or negative reply, basing on the needs of the other enterprise). The *IE* enterprises check if R&D process is finished and, in that case, get a competence in a random position (that can be already occupied by an owned competences, thus wasting the work done).

At step 4, the environment scatters the heat according to its parameters. Loop from step 1.

While the internal exploration behaviour is technically simply represented by some idle steps, after which an enterprise develops a new competence in a random position ℓ^{th} (based on a uniform distribution), the external exploration is a bit more complicated, and is metaphorically represented by the movement of a "probe", called "emissary", that searches the territory for the best possible match with other enterprises. The iterations behind the movement of the emissary are deterministic: it can move on the grid to follow the hottest cells. When an enterprise is found, its competence vector is analyzed, to see how many competences are possessed, that are missing to the parent enterprise. A quantum of heat is consumed at each step by the emissary, and when the heat is over, the enterprise with the best-found vector is asked for collaboration and competence exchange.

Parameters in the model

At the beginning of a simulation, the user can change the core parameters, in order to create a particular scenario to study. In Figure 1, the section of the control panel

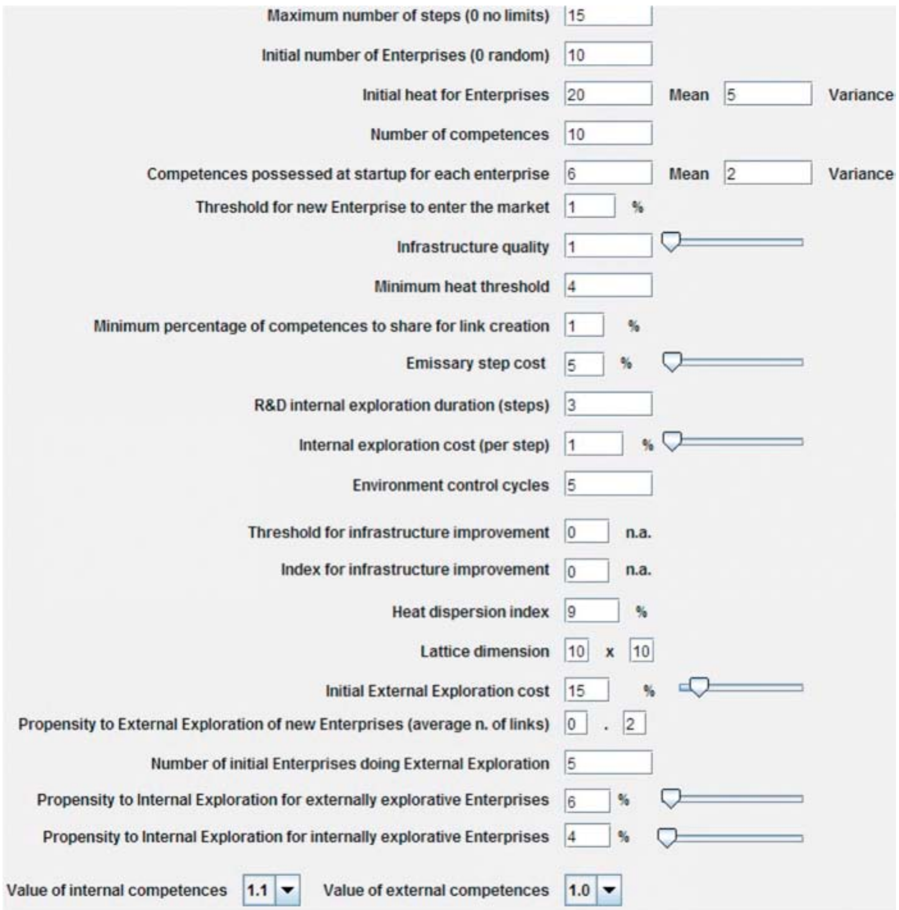

Figure 1.
The main control panel

containing the parameters is shown. Some of the parameters are constituted by a scalar value, others are in percentage, others are used to define stochastic (normal) distributions, given their mean value, and their variance. Here follows a synthetic explanation for the individual parameters:

- *Maximum number of steps*: is the number of iterations in the model. 0 sets the unbounded mode.
- *Initial number of enterprises*: is the number of enterprise agents present at start-up (0 is random).
- *Initial heat for enterprise*: a normal distribution setting the initial energy for each enterprise, given the mean and the variance.
- *Number of competences*: the length of the vector, equal for all the enterprises (metaphorically representing the complexity of the sector in which they operate).
- *Competences possessed at start-up*: a normal distribution referring to how many processes an enterprise owns internally, given the mean and the variance.
- *Threshold for new enterprise to enter the market*: a delta in the average heat of the world, after which a new enterprise is attracted in the market.
- *Infrastructure quality*: affects the cost of external exploration.
- *Minimum heat threshold*: level under which an enterprise cease.
- *Minimum percentage of competences to share for link creation*: when asked for a competences exchange, the other enterprise looks at this value to decide whether to create a link or not.
- *Emissary step cost*: percentage of the heat possessed by the enterprise spent for each step of its emissary, during external exploration task.
- *Internal exploration duration*: quantity of steps for internally developing a new competence.
- *Internal exploration cost*: percentage of the heat possessed by the enterprise spent for each step of internal exploration.
- *Environment control cycles*: quantity of steps for sampling the average heat of the environment.
- *Heat dispersion index*: percentage of heat evaporated at each step.
- *Lattice dimension*: the dimension of the grid hosting the enterprise (i.e. the whole environment).
- *Internal exploration cost*: una tantum cost for setting up an emissary for external exploration.
- *Propensity to external exploration for new enterprises*: when a new enterprise enters the market, it looks at the average number of links in the network. If more than this value, it behaves as externally explorative, otherwise internally explorative.
- *Number of initial enterprises, doing external exploration*: variable to divide the initial behaviour.
- *Value of internal/external competence*: reward (heat) given for each internal/external competence possessed.

Qualitative results

While the main object of this paper is to present the model itself as a tool for studying the effects of different managerial behaviour (externally or internally focused) on enterprise networks, in this paragraph some insights will be given about preliminary results obtained from the model itself. The presented ones will be mainly qualitative results, although the model can give many quantitative individual and aggregate results. In particular, a "computational only" mode is present in the model, allowing it to perform a multi-run batch execution. This is done according to the theory presented in Remondino and Correndo (2006): the model is executed a defined number of times (chosen by the user) and the different outputs are sampled and collected at every n steps (again, n decidable by the user) with the same parameters (in order to overcome sampling effects that could be caused by stochastic distributions) or by changing one parameter at a time by a discrete step, in order to carry on a *ceteris paribus* analysis on the model. While this kind of analysis will be discussed in detail in future works, here some qualitative and semi-quantitative outputs will be discussed, obtained from the model. The model can give the following different kinds of outputs, when running in "normal" mode (see Figure 2):

- A real-time graph, depicting the social network, in which the nodes are the enterprises, whose colour represent the behaviour they are following at a given step, and the links are the ties indicating two or more enterprises mutually exchanging one or more competences.
- A set of charts, showing in real time some core parameters, namely: average heat in the environment, number of links (in the network), number of links (average), number of enterprises doing internal exploration, number of ceased enterprises since the beginning, number of born enterprises since the beginning, number of available competences (overall), total number of skills possessed at the beginning, obtained by external exploration, obtained by internal exploration.
- A real time 2D map, showing emissaries and enterprises.

In Figures 3-5, the output graph is depicted at times 0 (no links), 100 and 500. These pictures belong to the same simulation, so the parameters are the same for all of them, with the only variation of time, giving a hint about the development of the enterprise network. In Figure 3 the initial state of the network is shown, where no ties have been created, yet. A total of 20 enterprises are on the territory, ten of which have an internally explorative behaviour and the other ten have an externally explorative mood. Internal competences are rewarded 10 percent more than external ones, but internal exploration strategy (e.g. research and development) is 30 percent more expensive.

After 100 steps (Figure 4) some new players have entered the market (an average of 1 new enterprise each ten steps), meaning that the average heat of the system increased significantly; this can be thought as a starting network, attracting new players thanks to a good overall balance. Some ties have formed and many new competences (the dimension of enterprises) have been internally produced.

After the initial steps in which 50 percent of the enterprise was doing internal exploration, now at the 100th step, only one third (i.e. 33 percent) is doing that, since almost all the smaller players are trying to outsource them from the bigger ones, in order to gain some energy. Unfortunately, many of these small enterprises have no

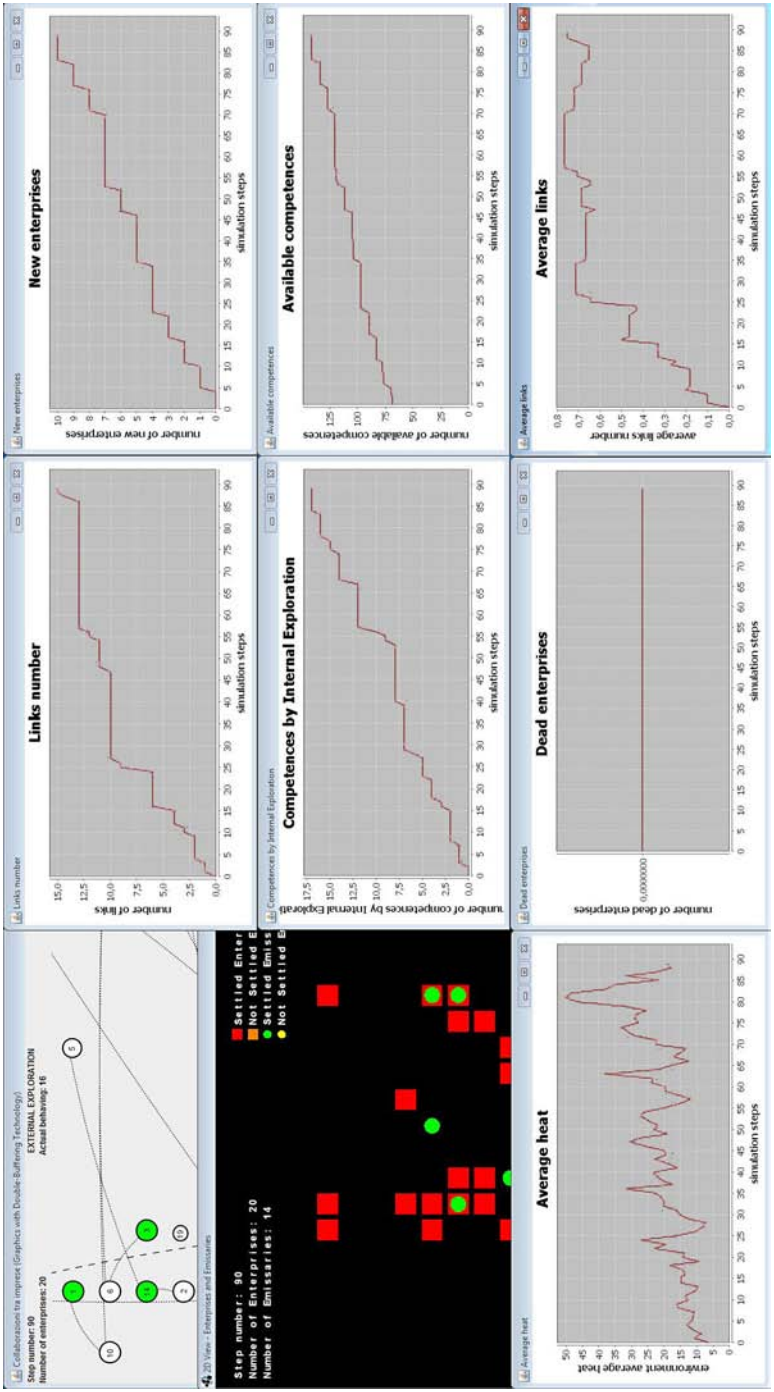

Figure 2.
Graphical output from the model

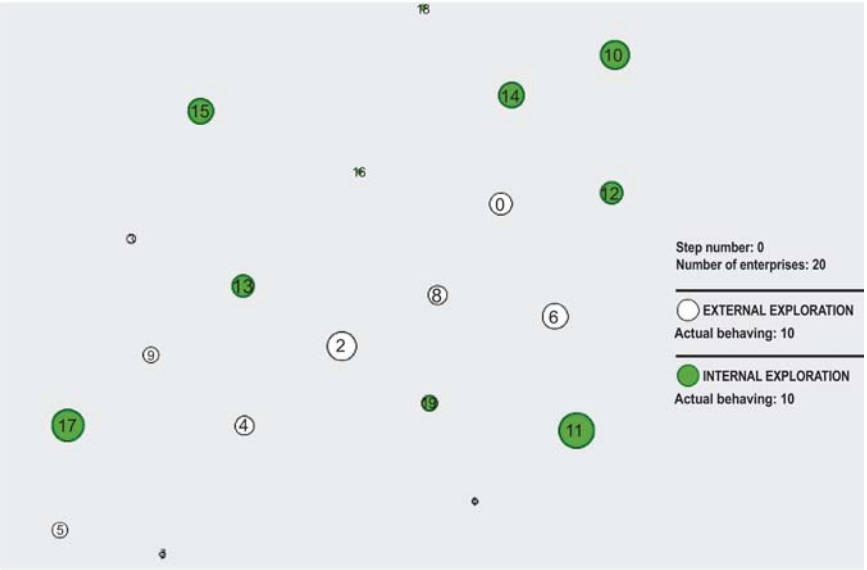

Figure 3.
The system at time 0

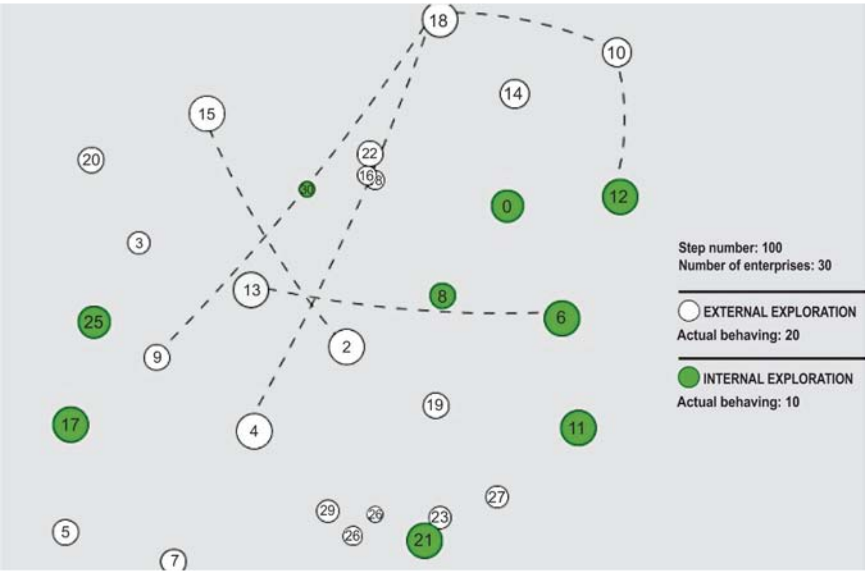

Figure 4.
The system at time 100

competence to give to the bigger one in exchange for theirs. They will eventually die (ceased enterprises) or try to change strategy, by starting an internal exploration. After time 100, an innovation occurs (by one of the enterprises).

The innovation triggers links formation; that is why after another 150 steps (see Figure 5) the total number of players increased again, at a higher rate than before (one every six steps, as an average) and now, in percentage, most of the surviving

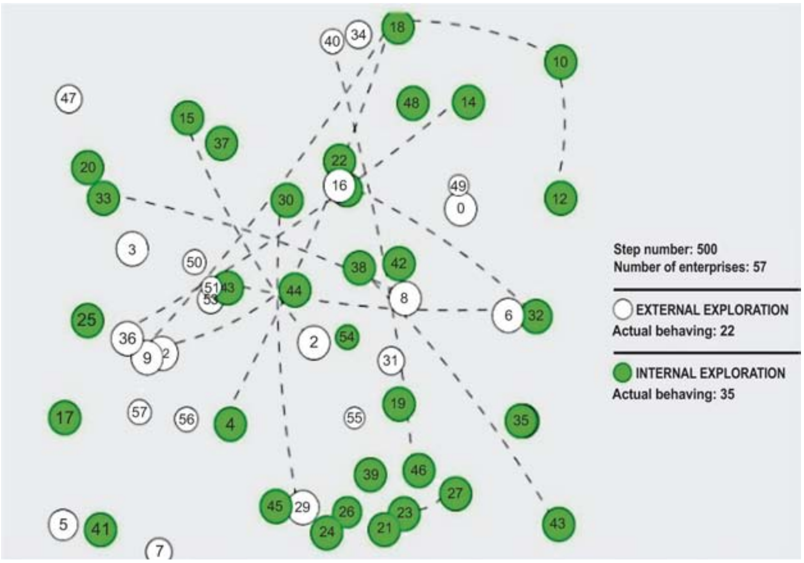

Figure 5.
The system at time 250 (150 steps since innovation)

enterprises are doing external exploration (62 percent circa) and have become quite big (many internal competences possessed). An innovation introduced in an existing network seems to turn most enterprises into externally explorative.

Notice that in this experiment the threshold under which an enterprise must cease is a low value, meaning that few of them have to leave the market. This was done intentionally to show how enterprises could react and adapt their behaviour even if they are modelled as reactive agents.

Conclusion and future works

An agent-based model is introduced, aiming at capturing the dynamics behind the creation and the following modifications of enterprise clusters for innovative competences exchange, i.e. networks in which enterprises can internally develop and/or share processes with other players. This is, by the way, one of the focal points behind the creation of industrial districts and clusters and is mainly dependent on the strategic management of the individual enterprises, namely externally or internally focused, and the optimal balance among these policies. A well-established network of this kind can attract new players, which will probably bring new knowledge and competences in it. The model is formally discussed, and so the agents composing it and its iterations. While studying quantitative results is beyond the purpose of this work, a qualitative analysis is given, and the network graph, one of the graphical outputs supplied by the model, is analyzed in order to show how network dynamics emerge from the model and its parameters, settable by the user. At the beginning, when the enterprises have few competences and high perception of how can be difficult develop and innovation process, they try to link with the enterprises that have already developed innovative processes. That is why, in an initial phase, the number of enterprises doing external exploration tends to increase. After some steps, the number of enterprises choosing external exploration is lower and lower and limited to the smallest players, or the newly arrived ones. The reason is that at the beginning, the enterprise's capability are low and the perception of the effort for developing a process innovation is high. The enterprise at this phase typically try to share and exchange competences with others that already developed an innovative process, not having to face the risk of inside developing, even if this can be more gainful in the long run. As time passes by, the enterprises start to become bigger and be more conscious about their capabilities and knowledge, thus reducing the perception of the effort to develop innovative processes internally.

The model is comprehensive and its scope is wide. In future works other features will be introduced, and quantitative analysis will be carried on in order to study real-world cases (e.g. existing industrial districts and so on) and the underlying dynamics that lead to their creations. Besides, a new feature will be implemented in the model, referred to as "shock mode", allowing the user to stop the model at a given step, and change some inner parameter, thus introducing innovations as explained at the end of paragraph 6. Also, agents' behaviour will be much more articulated; while in the present model agents simply react to some predefined rules, in order to choose which action to perform, in future works two new agent categories will be introduced: stochastic agents and cognitive agents. The former will base their behaviour on a uniform probability distribution, while the latter will adapt themselves, based on the payoff they get from their previous actions (trial and error learning technique). This will allow to capture even at a higher detail the effects on an enterprise network of a given management policy, adding realism to the behavioural choice.

Please notice that besides qualitative (or semi-quantitative) results as those shown in this article, the model could also output quantitative results to be applied to real-world scenarios.

In the future, our contribution will focus on extension of our model from E^3, that considers Environment, Enterprises and Emissaries, to E^n by the introduction of other kinds of agents. For example, we are studying the impact of financial system on network and cluster dynamics.

In a wider evaluation, the use of MAS as a methodology for analyzing real world situations and creating new theory, thus moving from the particular scenario to the general case, has some evident points of strength. First of all, since the model has to represent a scaled down situation, and not the whole reference system, it is quite easy to track down the data necessary to build the reference scenario. This reflects also on the fact that a limited range of real world data is used, thus preventing misleading aggregate results deriving from too many data, contributing to create white noise during the traditional analysis.

The most important feature of a model based on agent is the possibility of repeating the experiment several time, by changing one or few variables at a time, by leaving the other ones unchanged. This is referred to as "what if" analysis or "ceteris paribus" methodology. This has a double worthiness: on the one side, this can be used to track the cause-effect relationships among variables and results. On the other, it can be used to fine-tune the results in order to make it as reliable as possible, when compared to real world ones. In social observations, this kind of approach would be impossible. Human factor and changing context would simply make it unworthy to replicate experiments or measurements, unless the confidence interval is kept at a very large range.

This leads to the fact that from one base scenario, other scenarios can be created, if the right parameters are changed. The model presented in this work, which is focused on diffusion of innovation, could be easily extended to other strategic or economic phenomenon, by changing some core parameters. In this case, models based on MAS could have an important educational power; ranging from simple models, that could be perceived as games (e.g. business games) to be used into schools and universities, all the way up to complex models to be used for implicit knowledge formalization, knowledge transfer and management within enterprises. The "maieutilcal" approach allowed by a model of this kind is evident when dealing with organizational theories about Management and Economics: students can "learn by doing" using the model as an artifact on which carrying on their own experiments, thus directly discovering theories, without simply studying them by heart, and taking them as "dogmas" coming from books. In this way, the model becomes a virtual laboratory and the experiments could be done in a supervised (by teachers) or unsupervised way by the learners.

Note

1. The two most popular network theories are the one from Granovetter (1973) and the one from Burt (1982). These authors have implicitly based their theory on the work of Freeman (1979) regarding the advantage for social actors of being intermediaries or gatekeepers within a social structure. Granovetter's "strength of weak ties theory" can be summarized as follows: weak ties engender more information benefits than strong ties, because they are more likely to bridge otherwise disconnected clusters of actors than strong ties. Burt's structural hole theory extends the Granovetter theory by arguing that "tie weakness is a correlate, not a cause" of information benefits (Burt, 1982, p. 27).

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Corresponding author
Marco Pironti can be contacted at: pironti@di.unito.it